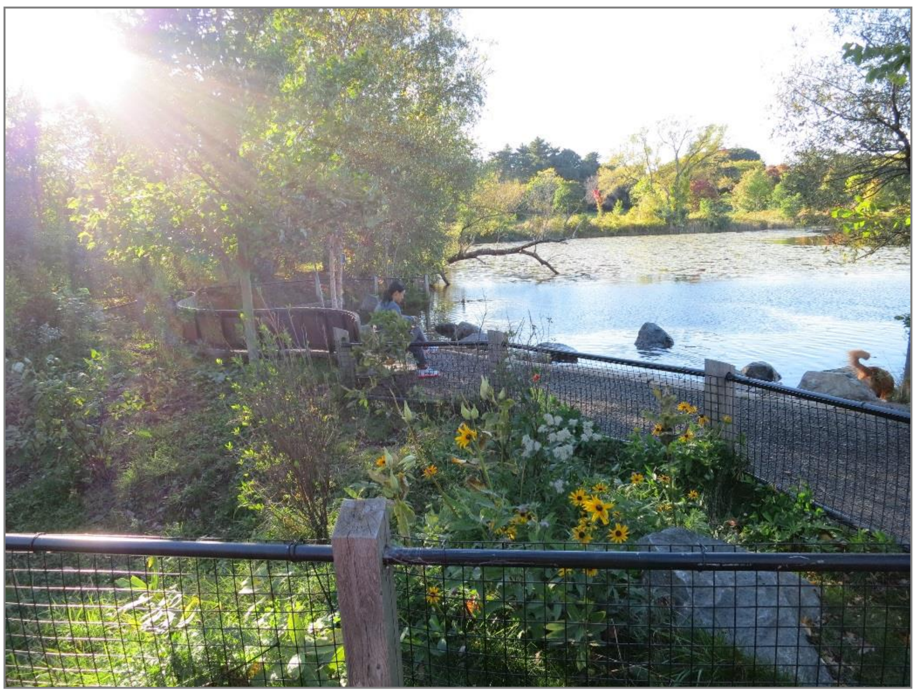
City of Cambridge Water Department 2015 Source Water Quality Report



Little Fresh Pond

September, 2016

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List of Abbreviations

CWD	Cambridge Water Department
DO	Dissolved oxygen
EPA	Environmental Protection Agency
HDPE	High density polyethylene
INDUST BROOK	Industrial Brook
JFA	Joint-Funding Agreement
LEX BROOK	Lexington Brook
MA DEP	Massachusetts Department of Environmental Protection
MassGIS	Massachusetts Office of Geographic Information
MCL	Maximum contaminant level
MPN	Most probable number
MWRA	Massachusetts Water Resource Authority
ORP	Oxidation reduction potential
QC	Quality Control
SMCL	Secondary maximum contaminant level
SPC	Specific conductance
TKN	Total Kjeldahl nitrogen
TSI	Trophic State Index
TDS	Total dissolved solids
TOC	Total organic carbon
TP	Total phosphorus
UMass	University of Massachusetts
USGS	United States Geological Survey

Executive Summary

This report presents the 2015 results of the City of Cambridge Water Department (CWD)'s Source Water Quality Monitoring Program, an ongoing study to assess source water quality in Cambridge reservoirs and associated tributaries. In 2015, water quality sampling was conducted year round in the City's three reservoirs: the Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs. Additionally, water quality data was collected from 12 streams feeding the reservoirs. Calendar year 2015 water quality monitoring results were compared against state and federal ambient and drinking water quality standards, as well as against EPA nutrient criteria guidelines. This report is intended to aid City managers and decision makers, and to educate those who are interested in the Cambridge water supply.

Reservoir waters in 2015 were of good quality and generally met Massachusetts Class A Surface Water Quality Standards. All surface samples from Fresh Pond Reservoir met the Class A standards. Stony Brook Reservoir and Hobbs Brook Reservoir surface samples generally met the MA Class A standards, although two percent of weekly *E. coli* samples (one sample) exceeded the 235 MPN standard at Stony Brook. In addition, surface samples from the August 6th Stony Brook profile sampling event and eight percent of weekly intake samples at Hobbs Brook and Stony Brook Reservoirs had pH levels above the 8.3 upper bound of the MA Class A standard. These elevated pH measurements occurred in late July and August (with the exception of one sample collected in early May) and may be attributable to algal photosynthesis; photosynthesis removes carbon dioxide from the water column thereby increasing pH. The bottom depths of all three reservoirs met MA Class A standards for temperature, pH, and *E. coli*. However, all three reservoirs were below the 5 mg/L Class A standard for dissolved oxygen (DO) during periods of reservoir thermal stratification in the summer months.

Low dissolved oxygen near the reservoir bottoms was coincident with increases in iron (Fe), manganese (Mn), and total phosphorous (TP). Iron and manganese are aqueous when reduced in low oxygen environments and phosphorous sorbed to iron sediments can be released into the water column. Chlorophyll-*a* (chl-*a*) in bottom samples from Hobbs Brook and Stony Brook Reservoirs increased steadily throughout the summer, likely due to the warmer water temperatures and phosphorus releases stimulating algal growth. However, increases in chl-*a*, which indicates algal growth, were not present in surface or bottom samples at the Fresh Pond Reservoir, the terminal reservoir in the Cambridge water supply system. The increase in TP observed in bottom samples from Fresh Pond was also minimal.

According to nearly every parameter monitored in 2015, Fresh Pond had the best water quality of the three reservoirs. One exception, however, was nitrate and ammonia, for which Fresh Pond had the highest median concentrations of the three reservoirs. Total nitrogen concentrations were also higher at Fresh Pond in 2015, although more data is needed to determine whether the elevated concentrations represent a trend. Nitrate levels at Fresh Pond were all less than 1.5 mg/L, which is far below the 10 mg/L MA Maximum Contaminant Level (MCL) set to protect human health.

Salt impairment is a serious concern in the Cambridge watershed. While all samples from the Stony Brook and Fresh Pond Reservoirs were below the chloride (Cl^-) Secondary Maximum Contaminant Level (SMCL) drinking water standard, over 20 percent of samples collected from the Hobbs Brook Reservoir were above the SMCL threshold value of 250 mg/L. The Hobbs Brook Reservoir is strongly influenced by runoff from salt-treated impervious surfaces, most notably Route 2 and Interstate 95. Stony Brook Reservoir and Fresh Pond Reservoir are supplemented by water stored in the Hobbs Brook Reservoir, so elevated salt concentrations at Hobbs Brook can translate into saltier water in the downstream reservoirs. In addition, sodium concentrations at all reservoirs were above the MA Secondary Drinking Water Guideline of 20 mg/L.

Tributary base-flow met Class A water quality standards, with a few notable exceptions. First, DO at the MBS sampling site was regularly below the MA Class A water quality standard of 5 mg/L. Water temperature in the Stony Brook tributary sample sites (Rt 20 and SB @ Viles) were warmer than the Class A temperature threshold of 20 degrees C for cold water fisheries in five of 12 sampling events. The Class A *E. coli* standard was also exceeded in 20 percent of tributary samples.

Tributary water quality reflected reservoir salt impairment. Fifty percent of tributary sites had median chloride concentrations above the MA SMCL of 250 mg/L. All tributary sites had median sodium levels in excess of the Secondary Drinking Water Guideline of 20 mg/L, ranging from 50 mg/L at Summer St to 483 mg/L at Lexington Brook.

Nutrient pollution is also a concern in the Cambridge watershed. While all tributary sites were well under the 10 mg/L MA MCL for nitrate, half of tributary sites had median concentrations above the EPA Nutrient Criteria of 0.31 mg/L. In addition, half of all tributary base-flow samples had median total phosphorus (TP) values above the EPA nutrient criteria. Many of these sites are downstream of wetland systems, which could be a natural source of phosphorus from wetland sediments. In addition, the WA-17 site had a median TP value above the EPA nutrient criteria and is downstream of a constructed stormwater treatment pond (online October, 2012), indicating that the pond was exporting phosphorus under baseflow conditions. Wet weather sampling conducted by the U. S. Geological Survey (USGS) at five tributary sites in the Cambridge Watershed found increased concentrations of TP during storm events, which demonstrates the importance of stormwater management in controlling phosphorus pollution.

An analysis of tributary pollutant loads and yields revealed that the Hobbs Brook Reservoir was more affected by stormwater pollution than the Stony Brook Reservoir. Nearly half of TP loading (48 percent) at Hobbs occurred during stormflow, whereas only 25 percent was attributable to stormflow at Stony. The majority of sodium, chloride, and nitrate loads at both reservoirs was attributable to base-flow. While total tributary pollutant loads were higher at Stony Brook Reservoir than at Hobbs Brook Reservoir due to the large drainage area of the Stony Brook Reservoir, nearly all pollutant yields were higher for tributaries discharging into the Hobbs Brook Reservoir. This reflects the highly developed landscape in the Hobbs Brook catchments. The one noticeable exception was nitrate, for which the Summer St catchment in the Stony Brook Reservoir watershed had the highest yield, likely attributable to golf course and residential fertilizer applications, as well as septic systems leaching.

In this study period, the Cambridge watershed received 40.87 inches of rain, as measured by the Cambridge Reservoir meteorological station. This is less than the 48.82 inch NOAA 1981-2010 Climate Normal for precipitation at the Bedford, MA Station. CWD finished (treated) water was supplemented by 7.9 million gallons (MG) of Massachusetts Water Resource Authority (MWRA) water during maintenance projects, amounting to less than one percent of annual demand. The Hobbs Brook Reservoir retention time, an estimate of total available supply, was 12 months. The average retention time of Stony Brook Reservoir was 18 days, with 2.4 billion gallons of water diverted to the Charles River. The amount of water diverted to the Charles River in 2015 was over 40 percent less than in 2014 due to drier than average conditions and less reliance on MWRA water (CWD, 2014). The residence time for Fresh Pond in 2015 period was approximately three and a half months. The combined residence time of the three reservoirs was approximately 16 months.

Introduction

This report describes the results of the City of Cambridge Water Department (CWD)'s source water quality monitoring efforts in calendar year 2015, part of a long-term study of the health and overall state of the City's drinking water supply.

The City obtains water from the Stony Brook watershed (referred to in this report as the Cambridge watershed) located in the towns of Lincoln, Weston, and Lexington and the City of Waltham. Water travels by gravity to the Walter J. Sullivan Purification Facility in Cambridge through a network of reservoirs, tributaries, and an underground aqueduct (Figure 1). The Cambridge watershed is relatively urbanized. Growth and development have the potential to negatively impact water quality. However, redevelopment projects may improve water quality by upgrading stormwater treatment systems in older parcels. The City of Cambridge only owns and controls approximately 10 percent of watershed lands. This lack of land ownership, along with the high development potential, requires collaboration with watershed stakeholders and regular water quality monitoring to ensure the long-term protection of the water supply.

The water quality monitoring program, as implemented, was designed by the U.S. Geological Survey (USGS), in cooperation with the Cambridge Water Department (CWD), and is based in part on the results of a 1997 - 1998 comprehensive assessment of reservoir and stream quality (Waldron and Bent, 2001). The assessment, conducted jointly by the USGS and the CWD, included a detailed analysis of the watershed and the identification of subbasins exporting disproportionate amounts of pollutants to the reservoirs. This information was then used to design the monitoring network which now makes up CWD's long-term source water quality monitoring program.

The USGS/CWD partnership continues to this day and funds "real-time" water quantity and quality monitoring stations, data collection, and interpretive analysis. All data by USGS is public record and can be retrieved online at this URL.

http://waterdata.usgs.gov/ma/nwis/current?type=cambrid&group_key=NONE&search_site_no_station_nm=&format=html_table

Purpose

The purpose of this report is to characterize Cambridge watershed source water quality for calendar year 2015. Obtaining long-term water quality information is essential in guiding watershed management practices and informing water treatment operations. By understanding where certain water quality problems exist, City resources can be better focused and targeted. Watershed staff can use water quality data to evaluate the efficacy of management initiatives and re-prioritize their efforts if necessary.

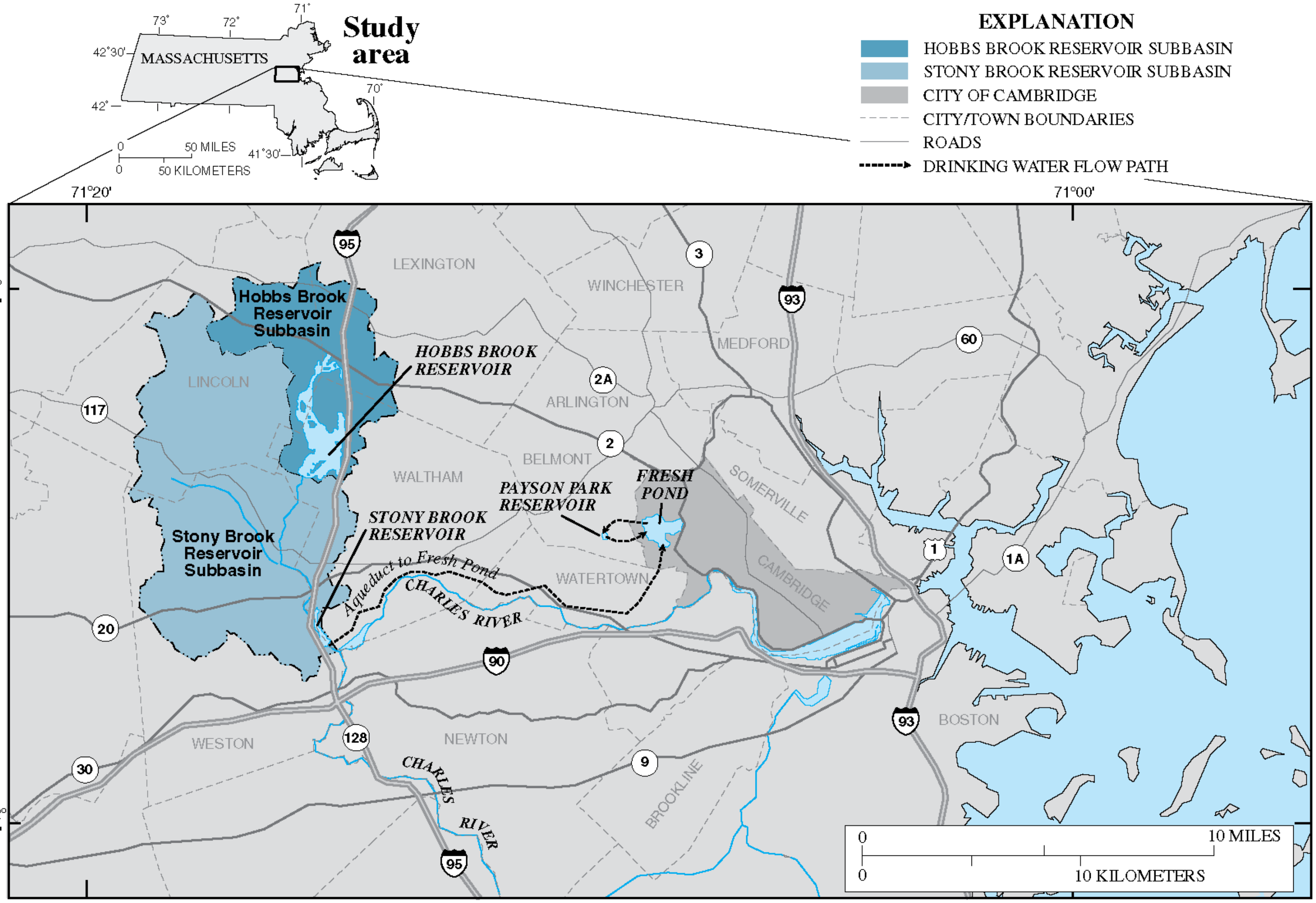

Figure 1. Cambridge Water Supply Source Area (Waldron and Bent, 2001)

Water Supply Network

The City of Cambridge obtains its water from the 24-square mile Stony Brook (Cambridge) watershed located in the towns of Lincoln, Weston, Lexington and the City of Waltham. This "upcountry" watershed is nested within the Charles River Basin and contains two major impoundments constructed in the 1890's, the Hobbs Brook and Stony Brook Reservoirs. The Hobbs Brook Reservoir (also known as the Cambridge Reservoir) receives water from a 7-square mile subbasin and discharges into Hobbs Brook through a gatehouse on Winter Street in Waltham. Hobbs Brook joins Stony Brook further downstream, which flows into the Stony Brook Reservoir on the Weston, Waltham town line. From the Stony Brook Reservoir, water is fed by gravity through a 7.5 mile underground pipeline to Fresh Pond, a kettle pond in western Cambridge, located in the Mystic River Basin.

During high flow periods (mainly winter and spring), the primary source area for the water supply is the Stony Brook Reservoir and its subbasin. During low flow periods (mainly summer and autumn), water is released at the Hobbs Brook dam to supply most of the City's daily water demand.

The Walter J. Sullivan Water Purification Facility within the Fresh Pond Reservation treats water from the Fresh Pond Reservoir. Treated water is pumped to Payson Park underground storage facility in Belmont, where it is then fed by gravity to the City's distribution system. Capacity at full pool for the Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs is roughly 2.5 billion, 418 million, and 1.5 billion gallons respectively.

In the event of an emergency, the City has a back-up connection to the MWRA (Massachusetts Water Resources Authority) supply. The MWRA supply was used exclusively during the construction of the current Water Treatment Plant from 1999-2001. In calendar year 2015, the City of Cambridge supplemented its supply during infrastructure repairs and maintenance in July and August. The amount of MWRA water purchased totaled 7.89 million gallons (MG) and represented less than one percent of total annual water demand.

Methodology

Monitoring Parameters and Standards

CWD monitors source water quality to assess general stream and reservoir health and to inform treatment plant operators during the water treatment process. Source water quality standards and guidelines used to assess water quality, as well as parameters monitored by CWD, are discussed in the following sections.

Comparative Water Quality Standards

CWD evaluated water quality against three different sets of standards and guidelines: Massachusetts Surface Water Quality Standards, Massachusetts Drinking Water Standards and Guidelines, and U.S. Environmental Protection Agency (EPA) nutrient criteria. A description of each set of standards or guidelines is provided below:

- ***Massachusetts Surface Water Quality Standards (Class A)*** *– Ambient surface water quality standards set by the Massachusetts Department of Environmental Protection (MA DEP) (314 CMR 4.00).*

These standards were created to implement the Massachusetts Clean Water Act, which requires MA DEP to define permissible uses for all water bodies in Massachusetts and to define minimum water quality criteria required to maintain those uses. All drinking water reservoirs and their associated tributaries are considered Class A; Class A water quality standards are intended to protect waterways for wildlife habitat and human contact.

- ***Massachusetts Drinking Water Standards and Guidelines*** *– Water quality standards for drinking water set by MA DEP (310 CMR 22.00) and the Massachusetts Office of Research and Standards (ORS).*

  Created to implement the requirements of the federal Safe Drinking Water Act, the Massachusetts Drinking Water Standards and Guidelines consist of Massachusetts Maximum Contaminant Levels (MA MCLs), Massachusetts Secondary Maximum Contaminant Levels (MA SMCLs), and Massachusetts Drinking Water Guidelines. The MA MCL and MA SMCL standards are developed by the EPA and adopted or made more stringent by the state of Massachusetts. Parameters in drinking water delivered to customers must not exceed the MA MCLs. Drinking water is not required to meet MA SMCLs unless deemed by MA DEP or EPA to be a threat to public health. While not mandatory for compliance, ORS Guidelines can help water suppliers monitor and address pollutants of concern that are not regulated by state or federal agencies. All MA MCLs, SMCLs, and ORS Guidelines apply to treated drinking water rather than untreated source water. However, these metrics are useful points of comparison to assess ambient water quality in the Cambridge watershed.

- ***EPA Nutrient Criteria*** *– Nutrient concentrations in lakes, reservoirs, and tributaries which have not experienced accelerated eutrophication due to anthropogenic nutrient inputs (reference conditions).*[1]

  The EPA developed these criteria to help states adopt nutrient water quality standards to maintain the uses defined by the Clean Water Act (U.S. Environmental Protection Agency 2000, 2001). Because Massachusetts does not include nutrients in its Class A Water Quality Standards, this report uses the nutrient criteria developed by EPA as a benchmark for assessing nutrient concentrations in the Cambridge watershed.

Parameters

Parameters monitored through the CWD Source Water Quality Monitoring program are discussed below.

<u>Massachusetts Surface Water Quality Standards (Class A)</u>

<u>*E. coli*</u> – This *E. coli* bacteria serotype is found in the digestive systems of warm-blooded animals and is used as an indicator for sewage-related pathogens. MA Class A ambient water quality standards state that

[1] It is assumed that the 25th percentile of median nutrient concentrations in lakes, reservoirs, and tributaries monitored by EPA in the relevant subregions of Ecoregion XIV represented reference conditions (U.S. Environmental Protection Agency 2000, 2001). The Cambridge watershed is located nutrient Ecoregion XIV and subregion 59. EPA encourages states to compare local conditions to the regional nutrient criteria and to develop nutrient criteria that are specific to conditions observed at the local level.

no single sample shall exceed 235 Colonies/100mL (measured as *most probable number* [MPN] by the CWD laboratory).

Dissolved Oxygen (DO) – Dissolved oxygen in water is critical to supporting a healthy fish and wildlife population. Low dissolved oxygen and anoxic conditions can mobilize nuisance metals such as iron and manganese and release nutrients from sediments. MA Class A ambient water quality standards state that dissolved oxygen should not be less than 6 mg/L in cold water fisheries and 5 mg/L in warm water fisheries, unless natural background conditions are lower.

pH – pH is a measure of acidity in water and is defined as the $-\log[H^+]$. Water with a pH level of 7 is considered neutral; water with a pH below 7 is acidic and above 7 is basic. The acceptable range of pH levels for Massachusetts Class A freshwater systems is 6.5 to 8.3, although pH levels must be no more than 0.5 units outside of the background range for the system. Waters with pH levels outside of this range can be harmful to fish and wildlife, and high pH levels can be indicative of algae blooms.

Temperature – Water temperature is an important metric for aquatic habitat suitability. Certain aquatic species are temperature sensitive and require cooler water to survive. Warmer water also holds less DO and can promote harmful biological growth such as algal blooms. The MA Class A maximum seven day average water temperature is 20 degrees C for cold water fisheries and 28.3 degrees C for warm water fisheries. The regulations also place limits on the temperature increases permissible from discharges. Exceptions to these standards are made for streams with naturally occurring higher temperatures.

Massachusetts Drinking Water Standards and Guidelines

The CWD source water monitoring program tests ambient water for a subset of MA MCL, SMCL, and ORS Guideline parameters. CWD performs more extensive testing on treated drinking water to ensure that all required standards and guidelines are met.

Nitrate and Nitrite as Nitrogen – Nitrate (NO_3^-) and nitrite (NO_2^-) are common inorganic forms of nitrogen. The drinking water maximum containment level (MCL), set to protect public health, is 10 mg/L; the EPA nutrient criteria is more restrictive at 0.05 mg/L for reservoirs and 0.31 mg/L for tributaries (See EPA Nutrient Criteria).

Chloride, Sodium, and Calcium – Sodium chloride (NaCl) is the most commonly used winter deicing agent in the Cambridge watershed. Calcium chloride ($CaCl_2$) is another deicing agent used in the watershed, although to a lesser extent than NaCl. Tracking chloride, sodium, and calcium levels in the water supply helps steer efforts to reduce their use and protect long term water quality. According to EPA, chloride is considered toxic to aquatic life at 230 mg/L (four day average, exceeded at least once every three years, considered chronic toxicity). Chloride concentrations in drinking water above 250 mg/L (MA SMCL) typically correspond with sodium levels high enough to impart a noticeably "salty" taste. The ORS Guideline for sodium is 20 mg/L. Calcium does not have guideline under the drinking water standards but is important to monitor given its presence in the deicing compound $CaCl_2$.

Iron/Manganese – Iron (Fe) and manganese (Mn) in drinking water are not considered health hazards but an excess can lead to staining and other aesthetic issues. These metallic elements are naturally-occurring in the earth's crust and soils. MA Secondary Maximum Contaminant Levels (SMCLs) are 0.3 mg/L for iron and 0.05 mg/L for manganese.

Total Dissolved Solids (TDS) – TDS is a measure of all organic and inorganic particles and ions dissolved in water. Elevated TDS levels can lead to taste, odor, or other aesthetic issues. The MA SMCL for TDS is 500 mg/L.

EPA Nutrient Criteria

Nutrients facilitate plant and algal growth and promote eutrophication (water body productivity). Excessive nutrient inputs can cause increased rates of eutrophication, leading to water quality impairments including, but not limited to, taste and odor problems and low dissolved oxygen availability for fish and wildlife.

Nitrate/Nitrite – see Massachusetts Drinking Water Standards and Guidelines

Total Kjeldahl Nitrogen (TKN) – TKN is the total of organic nitrogen and ammonia. The EPA nutrient criteria for TKN is 0.43 mg/L for reservoirs and 0.30 mg/L for tributaries. CWD also monitors ammonia concentrations separate from TKN.

Total Phosphorus (TP) – The EPA TP nutrient criterion is 0.02375 mg/L for streams and 0.008 mg/L for lakes/reservoirs. Phosphorus is believed to be the limiting nutrient for plant and algal growth in the Cambridge watershed. Phosphorous sorbed to sediment particles can be released into the water column under anoxic conditions, which can lead to excessive plant and algal growth, especially during the warm summer months.

Turbidity – Turbidity is a measure of water clarity. Turbid water often has increased levels of suspended dirt and organic matter, which can have adverse effects on water quality and aquatic habitat. The EPA nutrient criteria for streams in ecoregion 59 is 1.68 NTU. No turbidity nutrient criteria exists for reservoirs.

Other Parameters

Chlorophyll-*a* – The measured amount of chlorophyll-*a* in the water column is indicative of suspended algae biomass and is used to characterize a reservoir's productivity or trophic state.

Reservoir Trophic State (TSI) - Carlson's trophic state index (TSI) is a dimensionless numerical index ranging from 0 – 100, indicating the degree of nutrient enrichment of a water body (Table 1). TSI values less than 40 indicate a low productivity state (oligotrophic) and minimal external nutrient loading. Values ranging between 40 and 50 indicate moderate productivity (a mesotrophic state) and intermediate external nutrient loading. Values greater than 50 indicate a water body that is highly productive (eutrophic) and likely to produce algal blooms.

The TSI of a water body can be estimated using chlorophyll-*a* (chl-*a*) concentrations, TP concentrations, or measured secchi depths (SD). Since TSI is an estimator of algal biomass weight in the reservoir, chl-*a* is the best parameter for calculating TSI.

Table 1. Trophic State Index Explanation and Water Quality Implications

A list of possible changes that might be expected in a north temperate lake as the amount of algae changes along the trophic state gradient.

TSI	Chl (µg/L)	SD (m)	TP (ug/L)	Attributes	Water Supply
<30	<0.95	>8	<6	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion	Water may be suitable for an unfiltered water supply.
30 - 40	0.95 - 2.6	8 - 4	6 - 12	Hypolimnia of shallower lakes may become anoxic.	
40 - 50	2.6 - 7.3	4 - 2	12 - 24	Mesotrophy: Water moderately clear; increasing probability of hypolimnetic anoxia during summer.	Iron, manganese, taste, and odor problems worse. Raw water turbidity requires filtration.
50 - 60	7.3 - 20	2 - 1	24 - 48	Eutrophy: Anoxic hylpolimnia, macrophyte problems possible.	
60 -70	20 - 56	0.5 - 1	48 - 96	Blue-green algae dominate, algal scums and macrophyte problems.	Episodes of severe taste and odor possible.
70 - 80	56 - 155	0.25 - 0.5	96 - 192	Hypereutrophy: (light limited productivity). Dense algae and macrophytes.	
>80	>155	<0.25	192 - 384	Algal scums, few macrophytes.	

*http://www.secchidipin.org/tsi/htm#Relating%20Trophic%20State%20to%20the%20State%20of%20the%20Waterbody

Specific Conductance (SPC) – Specific conductance is the ability of water to conduct electrical current, normalized to 25°C. In the field, it is used as a surrogate for sodium and calcium chloride deicing agents. Abrupt changes in specific conductance can also be an indicator of pumping, dumping or other activities requiring investigation.

Total Organic Carbon (TOC) – TOC is used to quantify naturally-occurring organic matter in the water supply. When mixed with chlorine, carbon can react to form disinfection byproducts (haloacetic acids and trihalomethanes) regulated by Massachusetts Drinking Water Standards and monitored by CWD.

Monitoring Equipment

CWD measures *in situ* parameters, such as temperature, dissolved oxygen (DO), specific conductance, pH, and oxidation reduction potential (ORP), using a calibrated Eureka Water Probes Manta2™ Multiprobe. Grab samples are taken from streams and reservoirs using 1 Liter Teflon bottles for nutrients and high density polyethylene (HDPE) bottles for all other parameters. A peristaltic pump and pre-cleaned Tygon tubing is used for collecting bottom samples from the reservoirs. All samples are transported back to the Walter J. Sullivan Purification Facility on ice for processing. A contracted laboratory analyzes samples for TKN, ammonia, TP, and chlorophyll-*a*. The CWD laboratory performs the tests for all other parameters.

Monitoring Procedure and Schedule

Water samples for chemical analysis were collected at 12 tributary and 11 reservoir sampling stations using *Clean Water* protocols (Wilde and others, 1999) for all aspects of sample collection, preservation, and transport. For a more detailed discussion on the methods and process overview of the water quality monitoring program, refer to Appendix A.

Reservoir Sampling

Hobbs Brook Reservoir has four monitoring sites, two of which are sampled from the shoreline (HB @ Upper and HB @ Middle), and the other two (HB @ DH and HB @ Intake), are sampled by boat at fixed mooring locations (Figure 2). Stony Brook Reservoir has two sites sampled by boat (SB @ DH, and SB @ Intake), and Fresh Pond Reservoir has three sites (FP @ Cove, FP @ DH, FP @ Intake), all sampled by boat. The Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs were sampled between four and eight times to assess overall reservoir health in 2015 (Table 2).

Surface samples of chlorophyll-*a*, nutrients, bacteria, and selected metals were taken at each reservoir's deep hole (DH) buoy (deepest point of the reservoir) along with Secchi depth measurements. During periods of thermal stratification, additional samples were taken from the bottom layer (hypolimnion) of the reservoir. Depth profiles of dissolved oxygen, temperature, pH, and specific conductance were taken at both the DH sites and buoys close to the gatehouse intake structures. The profiles were used to monitor thermal and chemical stratification within the reservoirs, and to inform the operation of the aeration system at Fresh Pond (see the *Reservoir Water Quality* section for more information). *E. coli* bacteria samples were also collected at "intake" buoys.

In addition to the reservoir monitoring program, weekly surface grab samples are collected from inside the Hobbs Brook Dam gatehouse, or when the reservoir was frozen over, from the dam outlet (Table 2). Weekly grab samples are also collected from outside the Stony Brook Dam gatehouse intake. The weekly monitoring events help identify immediate contamination, capture seasonal and climatic water quality variability, and track chemical concentration changes over time. Weekly samples were analyzed primarily for *E. coli* bacteria, select metals, TOC, and specific conductance.

Table 2. Reservoir Sampling Program, 2015

Reservoir Monitoring Site	2015 Sample Frequency	Surface Grab*	Bottom Grab**	Depth Profile***
Hobbs Brook				
Upper	5x / yr	X		
Middle	5x / yr	X		
Deep Hole (DH)	5x / yr	X	X	X
Intake^	5x / yr	X		X
Gatehouse	Weekly	X		
Stony Brook				
Deep Hole (DH)	6x / yr	X	X	X
Intake^^	6x / yr	X		X
Gatehouse	Weekly			
Fresh Pond				
Deep Hole (DH)^^^	8x / yr	X	X	X
Intake^^^	8x / yr	X		X
Cove	7x/ yr			X

*Intake grab samples test for *E. coli* only. DH grab samples test for select metals and nutrients, turbidity, TOC, and chl-*a*. HB @ Middle and HB @ Upper grab samples include all previously mentioned tests.
**Only collected during periods of thermal stratification
***Depth profiles include measurments of temperature, pH, DO, TDS, ORP, and specific conductance.
^Only two intake profiles were collected in 2015 due missing anchor bouy.
^^Only five profiles collected due to missing anchor bouy.
^^^Seven sampling events included both a profile and grab sample, one event included only a profile.

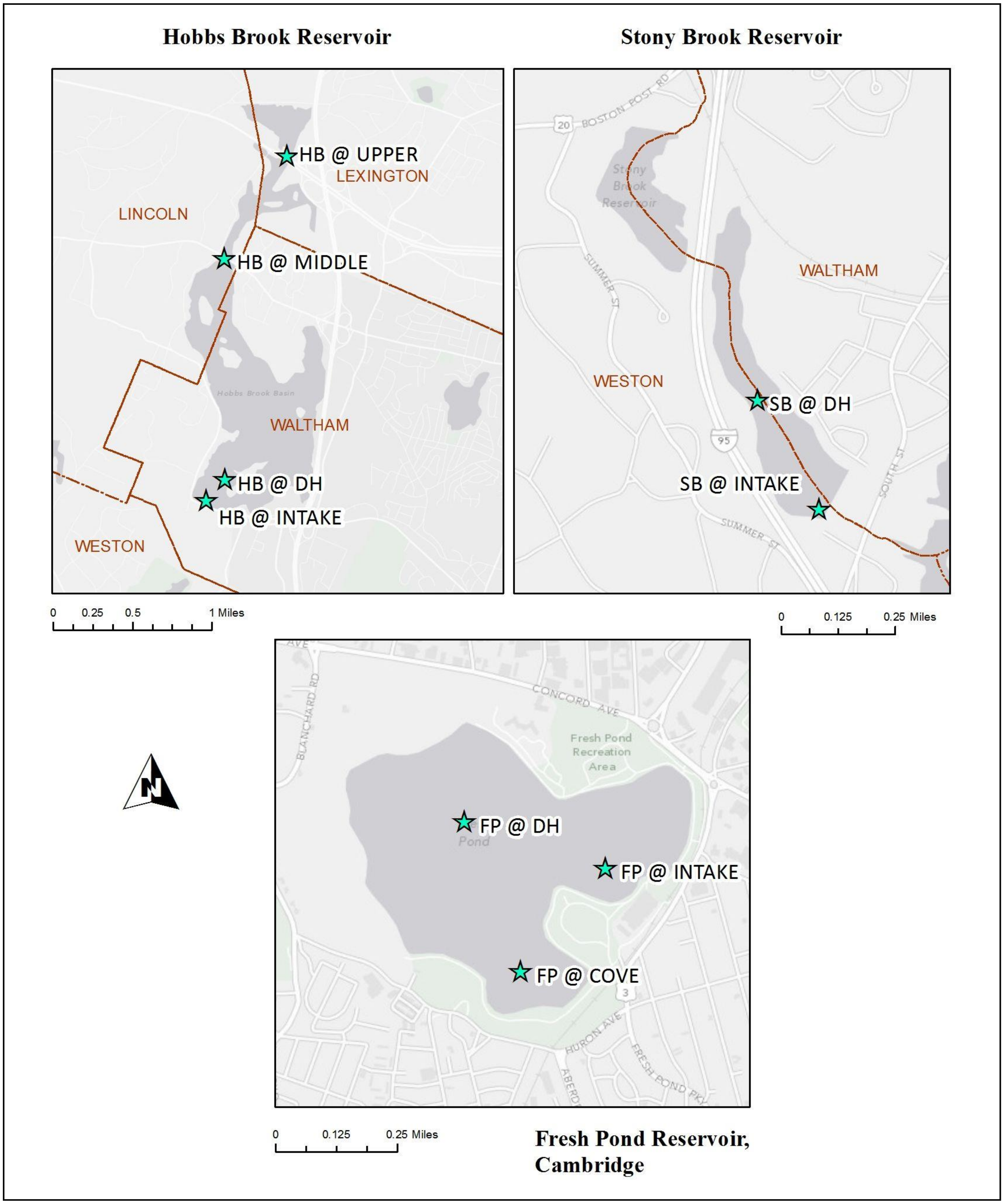

Figure 2. Reservoir Sampling Locations. HB @ Intake and SB @ Intake represents the sampling locations for both the periodic reservoir sampling and the weekly sample collected from the gatehouse intake.

Tributary Sampling

Twelve primary tributary sampling sites (Figure 3) were sampled five to six times under dry conditions in 2015 (see Appendix A for sampling dates). Samples were physically collected from the streams by the centroid dip technique (Edwards and Glysson, 1999). Samples were collected simultaneously by CWD and USGS staff at MBS on June 18th. Comparison of water quality results between the CWD and USGS samples serve as a broad quality control (QC) measure to gauge the variability in surface water samples, analysis methods, and collection techniques. See Appendix B for sample quality control results.

Nine of the 12 primary tributary sites were also equipped with USGS monitoring stations that continuously monitor stream stage, discharge (estimated based on stage), temperature, and specific conductance as part of a joint-funding agreement (JFA) between the CWD and USGS (Figure 3). Data from these sites are available on line in real time (http://waterdata.usgs.gov/ma/nwis/current/?type=cambrid&group_key=basin_cd&site_no_name_select=siteno).

The USGS took wet weather water quality samples one to seven times at five monitoring sites in 2015. These samples were used to assess water quality during storm events in the watershed tributaries. See Appendix A for the 2015 stormwater sampling schedule.

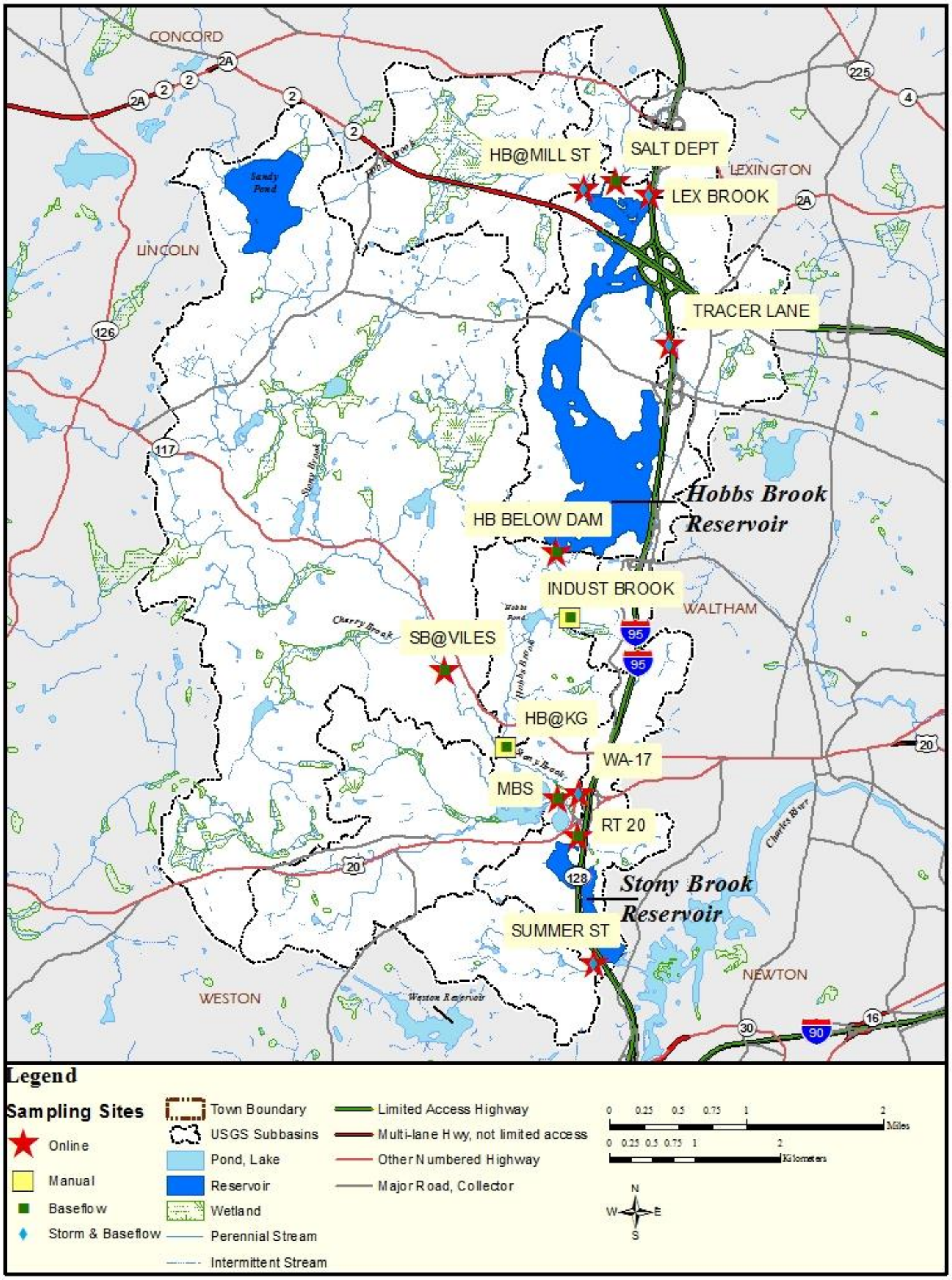

Figure 3. Tributary Monitoring Station Locations within the Cambridge Watershed

Load and Yield Calculations

The water quality monitoring program described above measures the concentration of pollutants in tributaries at specific points in time. However, the impact of a pollutant on reservoir water quality depends not only on pollutant concentration, but also on the volume of water discharging into the reservoir. For example, a small (low flow) tributary with a high salt concentration may contribute less sodium than a large (high flow) tributary with a lower concentration of sodium. Therefore, to account for the effect of tributary water volume on reservoir water quality, the annual load and yield of sodium, chloride, nitrate, and TP were calculated for each tributary that discharges directly into the Hobbs Brook and Stony Brook reservoirs, as well as WA-17. The annual load (total pollutant mass) and yield (load standardized by catchment area) were calculated separately for base-flow and stormflow using the formulas below:

$Load_{base\text{-}flow} = \mu_{CWD} \times Q_{base\text{-}flow}$

$Load_{stormflow} = \mu_{USGS} \times Q_{stormflow}$

Where:

μ_{CWD} = 2015 geometric mean concentration of Na^+, Cl^-, NO_3^-, or TP measured by CWD during dry conditions, in mg/L

$Q_{base\text{-}flow}$ = 2015 base-flow, in L/yr

μ_{USGS}[2] = 2015 geometric mean concentration of Na^+, Cl^-, NO_3^- or TP measured by USGS during storm events,[3] in mg/L

$Q_{stormflow}$ = 2015 stormflow, in L/yr

See Appendix C for the methodology used to separate base-flow and stormflow from total discharge at each site.

The following sections describe selected results of the water quality analyses conducted for all sampling locations in 2015.

[2] USGS did not perform stormwater sampling at the Salt Depot site during 2015. The mean stormflow concentrations of sodium, chloride, and TP from 2005-2007 (Smith, 2013) were used instead.

[3] USGS did not collect nitrate stormwater samples in 2015, so the CWD geometric mean nitrate concentration for base-flow was used as a proxy. According to Smith (2013), concentrations of total nitrogen are generally uncorrelated with streamflow. Therefore, CWD base-flow nitrate concentrations were used as a proxy for the stormflow concentration.

Reservoir Water Quality

Since the 1970s, CWD has been monitoring seasonal thermal stratification, which occurs in all three reservoirs with implications on water quality. In the spring, surface water begins to warm, forming a distinct upper layer (epilimnion) of less dense water that will not mix with colder, denser bottom waters (hypolimnion). Biochemical processes in the isolated bottom waters require oxygen and can create reduced (anoxic) conditions which stress fish and other aquatic fauna. Nuisance metals, such as iron and manganese, and nutrients normally bound to sediments can be released into the hypolimnion in the absence of oxygen. These metals and nutrients are then mixed throughout the water column during fall "turn over," the mixing of layers as surface water cools and water temperture becomes homogenious throughout the reservoir depth profile. Chemical stratification may also occur with cool, denser saline water trapped in the hypolimnion during the summer months. The following sections describe water quality in the Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs throughout all seasons in 2015.

Hobbs Brook Reservoir

The Hobbs Brook Reservoir is divided into three basins by State Route 2, Trapelo Road, and Winter Street (Figure 2). Unless otherwise noted, CWD staff conducted water quality sampling of the upper, middle, and lower basins five times in 2015 (Table 3). Additionally, 50 water quality samples were collected at the gatehouse intake.

As evaluated using the MA Class A Water Quality Standards, the water quality of the Hobbs Brook Reservoir was very good (Table 3). All criteria were met with the exception of 8 percent of weekly pH samples, all above the 8.3 Class A standard, and four of five bottom DO readings which were below the 5 mg/L criteria at the deep hole site. The elevated pH readings, one of which occurred on May 14th and the other three between July 23rd and August 20th, are likely due to algal photosynthesis. Photosynthesis removes dissolved carbon dioxide from the water column; because carbon dioxide often reacts with water to produce bicarbonate (HCO_3^-) and hydrogen (H^+), removal of carbon dioxide reduces the concentration of H^+ thereby increasing pH.

As expected, MA SMCL standards for finished (treated) water were exceeded more frequently than the MA Class A ambient (environmental) water quality standards. Iron and manganese were regularly exceeded in the middle and upper basins, but were exceeded in less than 20 percent of the lower basin surface samples (Table 3). It is possible that the relatively small volume of water in middle and upper basins results in higher concentrations, whereas the iron and manganese become more diluted in the lower basin. Additionally, the shallowness of the middle and upper basins allows for greater penetration of wind, which could suspended sediments with high iron and manganese content. Despite observed reservoir exceedances of iron, manganese, and TDS, finished (treated) water in Cambridge meets and/or exceeds these aesthetic SMCL standards.

Twenty-two percent of weekly intake samples exceeded the SMCL for chloride, whereas no weekly samples in 2014 excceded this standard (CWD, 2014). Increasing sodium and chloride concentrations are a concern since they cannot be removed using technologies currently employed by CWD.

All samples from the middle and upper Hobbs exceeded the recommended EPA nutrient criteria for TP, whereas only two of five surface samples exceeded the criteria at the lower basin HB @ DH hole site (Table 3). Additionally, the HB @ DH surface site had the lowest median TP concentrations of all reservoir sampling sites in the watershed (Table 14, Reservoir Water Quality Comparision). This suggests that water quality improves as water travels through the three basins of the Hobbs Brook Reservoir, likely due to the settling of solids and dillution in the larger lower basin. Exceedence results for nitrate and TKN are shown in Table 3 and also demonstrate a trend of decreasing frequency of exceedences between the upper, middle, and lower basins.

Table 3. Hobbs Brook Reservoir Summary of Exceedances, 2015

Standard	Parameter	Standard	Periodic Reservoir Sampling Sites					Weekly Sample Site
			HB @ Upper	HB @ Middle	HB @ DH Surface	HB @ DH Bottom^^	HB @ Intake Surface	Outlet (intake) Samples
MA Class A Water Quality	DO	> 5 mg/L	0%	0%	0%	80%	0%***	NS
	Temp	< 28.3 °C	0%	0%	0%	0%	0%***	NS
	pH	Between 6.5 - 8.3	0%	0%	0%	0%	0%***	8%
	E.coli, single sample	< 235 MPN	0%	0%	NS	NS	0%	0%
MA Secondary Maximum Contaminant Level (SMCL)	Cl^-	< 250 mg/L	50%*	40%	60%	0%	NS	22%
	Mn	< 0.05 mg/L	100%	60%	0%	75%	NS	18%
	Fe	< 0.3 mg/L	100%	100%	0%	50%	NS	4%
	Total Dissolved Solids (TDS)*	< 500 mg/L	60%	80%	100%*	100%	100%^	NS
MA Secondary Drinking Water Guidelines	Na^+	< 20 mg/L	100 %	100 %	100 %	100 %	NS	100 %
EPA Nutrient Criteria for Upper Watershed	$NO_3^- + NO_2^-$ - N	< 0.05mg/L	50%*	60%	0%*	0%**	NS	NS
	TKN	< 0.43 mg/L	100%	100%	0%	75%	NS	NS
	TP^^^	< 0.008 mg/L	100%	100%	40%	75%	NS	NS
Number of Sampling events			**5**	**5**	**5**	**4, 5**	**5**	**50**

NS = Not sampled for parameter

*Four, not five, samples were collected due to field equipment failure or laboratory error; **Three samples analyzed; ***Two measurements; ^Represents a single measurement

^^HB @ DH Bottom was sampled five times in 2015 for MA Class A Water Quality Standards unless otherwise noted. It was sampled four times for all other parameters unless otherwise noted.

^^^The detection limit for TP was 0.010 mg/L, which is above the EPA nutrient criteria. For the purposes of this analysis, it was assumed that sample results below the detection limit were below the EPA nutrient criteria.

In a typical year, the water column at HB @ DH site shows signs of thermal and chemical stratification in April and fully stratifies by July. The water column generally mixes by November and exhibits relatively uniform temperature, although dissolved oxygen concentrations may still decrease with increasing depth, indicating incomplete physical mixing.

2015 depth profiles exhibit the expected behavior of thermal stratification during the summer months (June – September profiles, Figure 4) and complete mixing conditions in colder months (December profile, Figure 4). Winter profiles were not collected January through April of 2015 when winter weather conditions made profiles difficult and unsafe to obtain. Slight winter stratification may occur during years with ice cover, but this stratification tends to be less stable than summer stratification due to the coldest layer forming on top of the denser 4°C layer on bottom. The decreased stability may allow more mixing between layers and may prevent anoxic conditions from forming in the bottom layer.

Specific conductance profiles consistently increased each month from June through September, with chemical stratification evident in the September profile (Figure 4). The observed increase in specific conductance could be the result of road salt applied during the winter moving through the watershed, as well as warmer and drier weather increasing evaporation and minimizing the dilution of salt entering the Hobbs Reservoir from groundwater.

The June and July profiles, which were beginning to show thermal stratification, had DO levels in the hypolimnion below 5 mg/L, the Class A water quality standard. Anoxic conditions were observed in the hypolimnion during August and September when the thermal stratification was most pronounced. Nutrients and metals common in low oxygen, reducing environments were present in the highest concentrations during the September 3rd sampling event (Table 4). The bottom water quality sample had elevated levels of iron (4.10 mg/L), manganese (7.70 mg/L), TKN (1.8 mg/L), TP (0.09 mg/L), and ammonia (0.43 mg/L). The sample also contained high turbidity (20 NTU) and high chl-*a* (117 mg/m^3), which indicate a subsurface algal bloom or contamination of the sample by bottom sediments with benthic algae. The dramatic increase in turbidity between August and September suggests possible sediment contamination (Table 4).

Table 4. Chl-*a*, Turbidity, and Select Nutrient and Metals from Bottom Samples at Hobbs Brook Reservoir During Thermal Stratification, 2015

Date	Chl-*a* (mg/m^3)	NH_3 (mg/L)	TKN (mg/L)	TP (mg/L)	Mn (mg/L)	Fe (mg/L)	Turbidity (NTU)
6/11/2015	2.47	0.35	**0.54**	**0.013**	**0.953**	0.237	1.19
7/9/2015	3.60	0.08	0.35	< 0.010	0.012	0.134	0.43
8/6/2015	17.0	0.16	**0.51**	**0.019**	**2.28**	**0.996**	2.88
9/3/2015	117	0.43	**1.8**	**0.090**	**7.70**	**4.10**	20.0

TKN, TP, Mn and Fe values that exceed the EPA nutrient criteria or MA SMCL are bolded. Although the detection limit for TP was above the EPA criteria, it was assumed that samples below the detection limit were below the EPA nutrient criteria threshold.

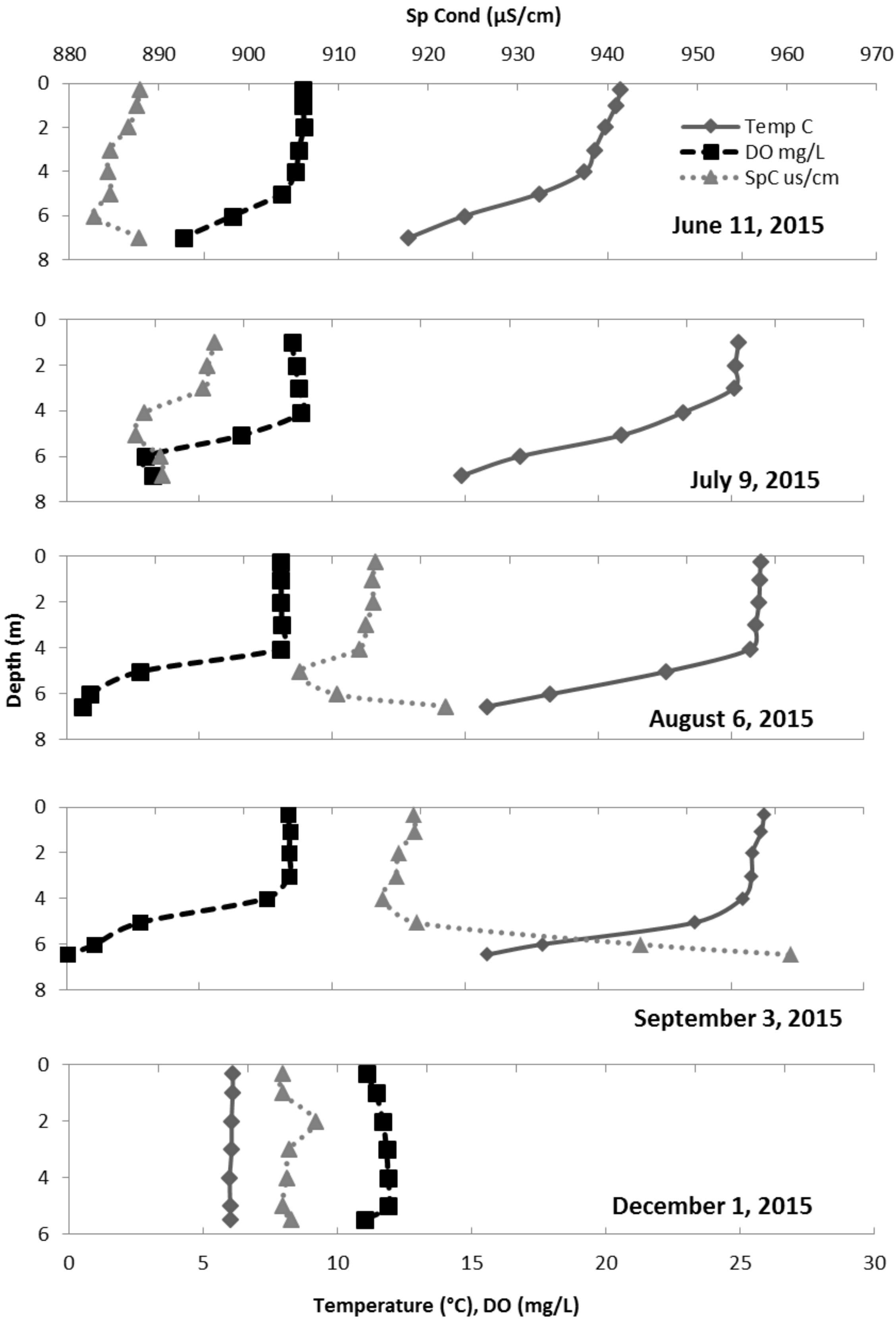

Figure 4. Hobbs Brook @ Deep Hole (HB @ DH) Depth Profiles, June-December 2015

Stony Brook Reservoir

The Stony Brook Reservoir is bisected by Interstate 95, with twin box culverts under the interstate directly connecting the two basins. Samples are taken from the deepest part of Stony Brook (SB @ DH) and at the southern gatehouse (SB @ INTAKE, Figure 2). Samples are not taken from the upper portion of the reservoir due to lack of boat access.

Water-column sampling at the Stony Brook Reservoir was conducted by CWD staff six times in 2016. Stony Brook has an aeration system designed to aid mixing throughout the reservoir and to help avoid thermal stratification and anoxic conditions from forming in the hypolimnion. Historically, the aeration system operates during the spring, summer, and fall months. However, the system was shut down after compressors failed in July 2014 and has remained offline since.

Weekly surface samples taken from the Stony Brook Reservoir met all Class A water quality standards with the exception of 2 percent of weekly *E. coli* samples (one sample), 8 percent (four samples) of weekly intake pH samples, and the deep hole and intake surface measurements on August 6th (Table 6). The four weekly intake samples were above the Class A pH 8.3 upper bound and occurred between July 23 and August 20th. This suggests that the elevated pH was due to algal growth. The August 6th profiles at SB @ DH and SB @ Intake also had pH levels above 8.3, with an elevated chl-*a* at the SB @ DH site[4], supporting the explaination of elevated pH due to algal activity.

Water quality at the bottom of the SB @ DH site met the Class A criteria for temperature, pH, and *E. coli*. However, the bottom was anoxic during the warm summer months, likely due to the thermal stratification which prevents mixing with the more oxygenated surface water (Figure 5).

Unlike the Hobbs Reservoir, no samples from the Stony Reservoir exceeded the MA SMCL for chloride, yet approximately half of profiles had TDS in excess of the MA SMCL (Table 6). Similar to the Hobbs Reservoir, anoxic bottom conditions occurred alongside elevated chl-*a*, manganese, iron, TKN, and TP (Table 5). Concentrations of these parameters increased throughout the summer. The effect of the anoxia was especially pronounced in August and September, when iron and managanese concentrations were higher than any other surface or bottom samples from 2015. Increasing levels of chl-*a* and turbidy indicate subsurface algal growth throughout the summer. CWD will continue to monitor the effects of stratefication on overall water quality to inform future decisions on whether or not to repair the aeration system.

Table 5. Chl-a, Turbidity, and Select Nutrient and Metals from Bottom Samples at Stony Brook Reservoir During Thermal Stratification, 2015

Date	Chl-*a* (mg/m^3)	NH_3 (mg/L)	TKN (mg/L)	TP (mg/L)	Mn (mg/L)	Fe (mg/L)	Turbidity (NTU)
6/11/2015	<2.00	0.31	**0.49**	**0.025**	**0.994**	0.002	1.18
7/9/2015	7.74	0.37	**0.85**	**0.020**	**1.84**	**0.508**	1.16
8/6/2015	13.8	0.98	**1.3**	**0.025**	**6.47**	**8.83**	3.03
9/3/2015	39.5	1.45	**2.0**	**0.040**	**9.89**	**19.1**	10.0

TKN, TP, Mn and Fe values that exceed the EPA nutrient criteria or MA SMCL are bolded.

[4] Duplicate chl-*a* samples were collected at SB @ DH, the average of which was 18.00 mg/m^3. However, the relative percent difference between the two samples was over 150 percent. One sample was 4.20 mg/m^3 and the duplicate sample was 31.9 mg/m^3.

Despite elevated bottom metals and nutrient concentrations, thermal stratification at the Stony Brook Reservoir appeared less pronounced than at the Hobbs Brook Reservoir, perhaps due to the shorter residence time of water in Stony compared to Hobbs (see Reservoir Retention Time). The specific conductance profiles at the Stony Brook Reservoir were lower than in the Hobbs Brook Reservoir, which is likely due to the less developed nature of the Stony subwatershed and less loading from road salts. There is slight chemical stratification in August, with denser, saltier water towards the bottom of the reservoir. The chemical stratification is gone in the September profile, and the reservoir has undergone thermal mixing by October.

Table 6. Stony Brook Reservoir Summary of Exceedances, 2015

Standard	Parameter	Standard	Periodic Reservoir Sampling Sites			Weekly Samples
			SB @ DH Surface	SB @ DH Bottom^	SB @ Intake	Output (Intake) Samples
MA Class A Water Quality	DO	> 5 mg/L	0%	67%	0%*	NS
	Temp	< 28.3 °C	0%	0%	0%*	NS
	pH	Between 6.5 - 8.3	17%	0%	20%*	8%
	E.coli, single sample	< 235 MPN	NS	NS	0%	2%
MA Secondary Maximum Contaminant Level (SMCL)	Cl^-	< 250 mg/L	0%	0%	NS	0%
	Mn	< 0.05 mg/L	67%	100%	NS	82%
	Fe	< 0.3 mg/L	0%	75%	NS	24%
	Total Dissolved Solids (TDS)*	< 500 mg/L	40%*	60%*	50%**	NS
MA Secondary Drinking Water Guidelines	Na^+	< 20 mg/L	100 %	100 %	NS	100 %
EPA Nutrient Criteria for Upper Watershed	$NO_3^- + NO_2^-$ - N	< 0.05mg/L	60%*	33%***	NS	NS
	TKN	< 0.43 mg/L	0%	100%	NS	NS
	TP^^	< 0.008 mg/L	50%	100%	NS	NS
Number of Sampling Events			**6**	**4, 6**	**6**	**50**

NS = Not sampled for parameter
*Five, not six, samples were collected due to field equipment failure or laboratory error
**Sampled four times
***Sampled three times
^SB @ DH Bottom was sampled six times in 2015 for MA Class A Water Quality Standards and TDS and four times for all other parameters unless otherwise noted. ^^The detection limit for TP was 0.010 mg/L, which is above the EPA nutrient criteria. It was assumed that sample results below the detection limit were below the EPA nutrient criteria. However, one sampling event had a result of 0.011 mg/L while the field duplicate was <0.01 mg/L. This event was considered an exceedance.

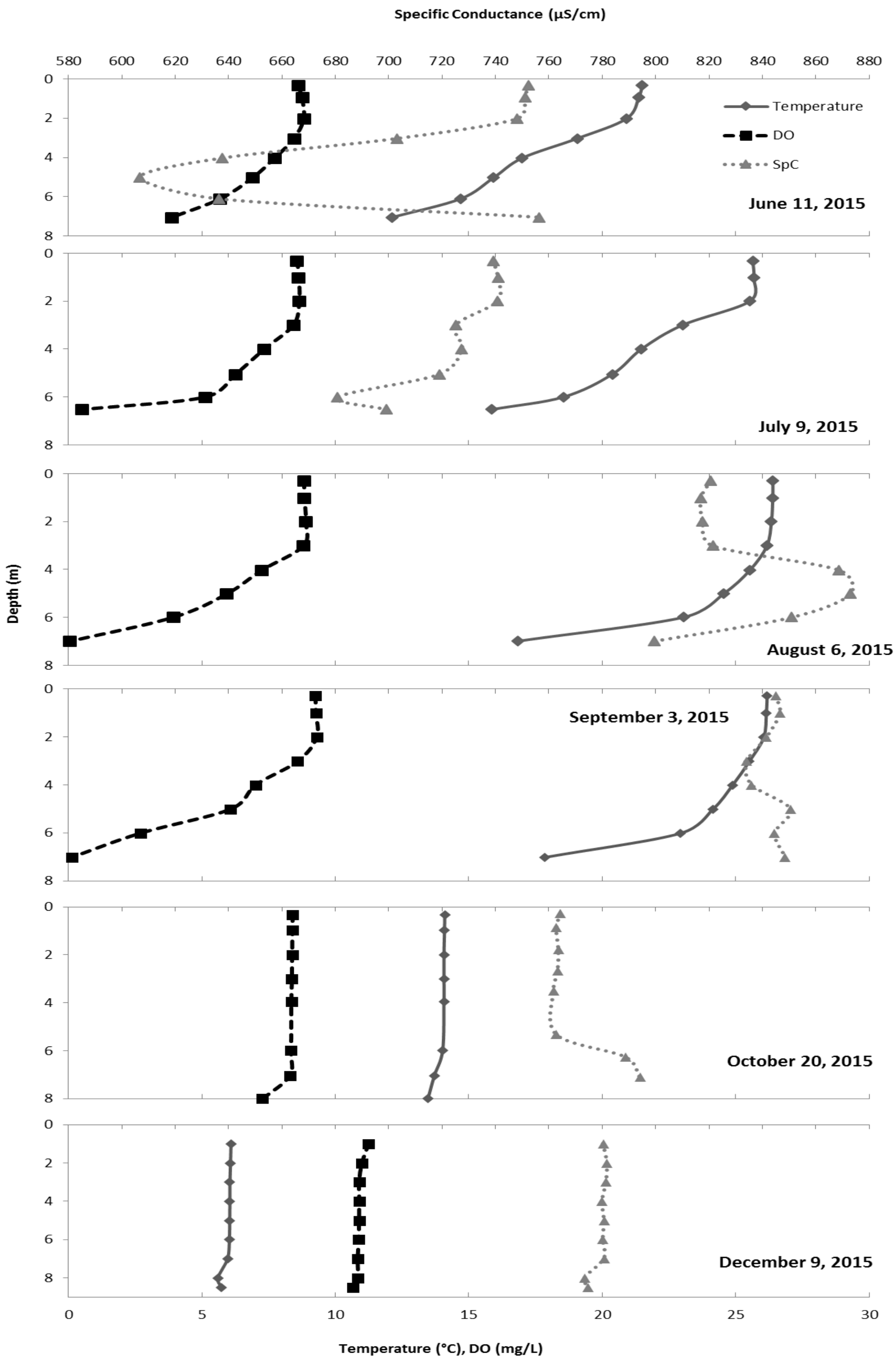

Figure 5. Stony Brook @ Deep Hole (SB @ DH) Depth Profiles, June-December 2015

Fresh Pond Reservoir

Monitoring and managing thermal stratification is particularly important in Fresh Pond because it is the terminal water supply reservoir in the system. Water is pumped directly from Fresh Pond and treated in the Walter J. Sullivan Purification Facility for potable uses. Spikes in nuisance metal concentrations, if not controlled in a timely fashion through the treatment process, could produce drinking water with taste, odor, color, or other aesthetic issues. An aeration system at Fresh Pond operates continuously overnight throughout spring and summer until the autumn turnover to help avoid anoxic conditions in the reservoir. Thorough cleaning and maintenance of the lines was performed in July 2015.

Water quality surface grab samples were collected seven times and bottom grab samples were drawn four times in 2015. Water-column profiles were taken a total of eight times to monitor reservoir stratification and guide aeration system management.

By nearly all standards and guidelines, Fresh Pond had the best water quality of the three reservoirs. All surface samples taken from Fresh Pond met Class A water quality standards for DO, temperature, pH, and *E. coli* (Table 7). Only the August and September profiles had bottom DO levels below the Class A standard of 5 mg/L, while all bottom profiles met the Class A standard for temperature and pH.

Fresh Pond met the MA SMCLs for iron and chloride in all bottom and surface samples collected in 2015 (Table 7). It also met the SMCL for TDS with the exception of one sampling event in October (14 percent of samples) (Table 7). The MA SMCL for manganese, however, was exceeded in 43 percent of surface samples and 100 percent of bottom samples at FP @ DH. The highest levels of manganese occurred in the bottom samples during August (1.22 mg/L) and September (4.10 mg/L) when the pond was the most strongly thermally stratified and had low DO, despite the running of the aeration system (Table 8 and Figure 6).

In general, even with the aeration system running, Fresh Pond will start to stratify in April and will begin to mix towards the end of September or beginning of October, depending on the severity of the summer. In 2015, Fresh Pond was stratified beginning in April (Figure 6). The aeration system helped to reduce stratification June through October. The aeration system was shut off in October after the profile demonstrated that the reservoir was fully mixed. Specific conductance in Fresh Pond is similar to Stony Brook, the reservoir from which it is directly supplied. The specific conductance readings tended to increase throughout the year, reflecting the chemistry of the upper reservoirs.

Table 7. Fresh Pond Reservoir Summary of Exceedances, 2015

Standard	Parameter	Standard	FP @ DH Surface*	FP @ DH Bottom**	FP @ Intake*
MA Class A Water Quality	DO	> 5 mg/L	0%	25%	0%
	Temperature	< 28.3 °C	0%	0%	0%
	pH	Between 6.5 - 8.3	0%	0%	0%
	E. coli (single sample)	< 235 MPN	NS	NS	0%
MA Secondary Maximum Contaminant Level (SMCL)*	Cl^-	< 250 mg/L	0%	0%	NS
	Mn	< 0.05 mg/L	43%	100%	NS
	Fe	< 0.3 mg/L	0%	0%	NS
	Total Dissolved Solids (TDS)	< 500 mg/L	14%	14%	14%
MA Secondary Drinking Water Guidelines	Na^+	< 20 mg/L	100%	100%	100%
EPA Nutrient Criteria for Upper Watershed	$NO_3^- + NO_2^-$ - N	< 0.05mg/L	100%	100%	NS
	TKN	< 0.43 mg/L	14%	25%	NS
	TP	< 0.008 mg/L	29%	25%	NS
Number of Sampling events			**7, 8**	**4, 7, 8**	**7, 8**

NS = Not sampled for parameter
* Sampling was conducted eight times for DO, temperature, and pH. All other parameters were sampled seven times unless otherwise noted.
** Sampling was conducted eight times for DO, temperature, and pH. TDS was sampled seven times. All other parameters were sampled four times.

Table 8. Chl-a, Turbidity, and Select Nutrient and Metals from Bottom Samples at Fresh Pond Reservoir During Thermal Stratification, 2015

Date	Chl-*a* (mg/m^3)	NH_3 (mg/L)	TKN (mg/L)	TP (mg/L)	Mn (mg/L)	Fe (mg/L)	Turbidity (NTU)
3/2/2015	<2.00	0.057	<0.50	<0.01	**0.133**	0.141	0.40
6/24/2015	<2.00	0.090	0.34	<0.01	**0.092**	0.070	0.426
8/13/2015	<2.00	0.065	0.40	<0.01	**1.22**	0.110	1.60
9/15/2015	<2.00	0.15	0.34	**0.02**	**4.10**	0.083	0.52

TKN, TP, Mn and Fe values that exceed the EPA nutrient criteria or MA SMCL are bolded. It was assumed that samples below the detection limit were below the EPA nutrient criteria threshold.

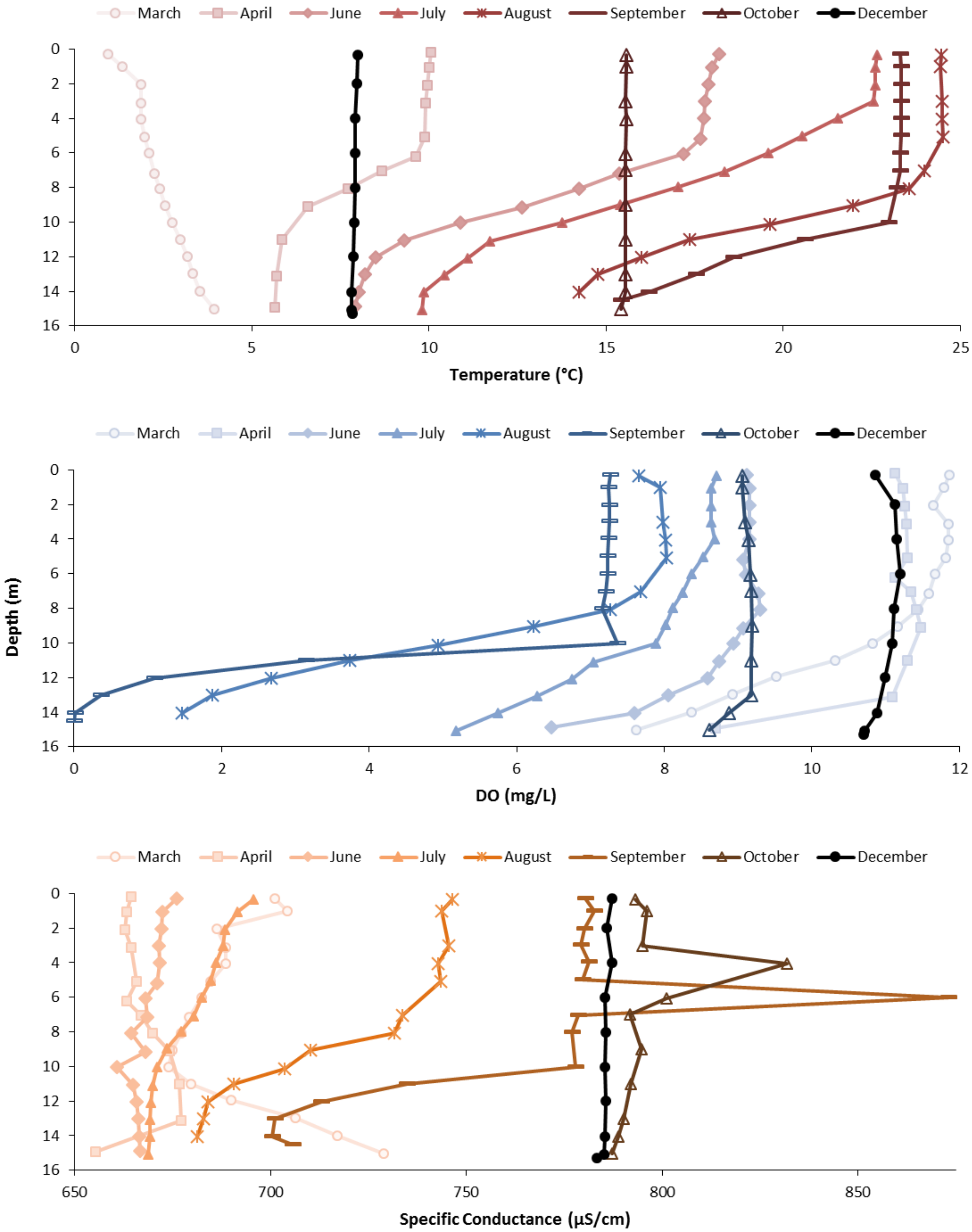

Figure 6. Fresh Pond at Deep Hole (FP @ DH) Profiles March-December 2015

Reservoir Water Quality Comparison

The Cambridge water supply system exhibits an overall cascade effect as water travels from Hobbs Brook Reservoir to Fresh Pond. Settling and dilution occur as water passes through the upper and middle basins of the Hobbs Brook Reservoir to the deep hole site (HB @ DH) in the lower basin. By the time source water reaches Fresh Pond, it is relatively free of suspended solids.

As shown in Figure 7, median TSI values for the deep hole surface sites at Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs were 37, 41, and 37, respectively. These values indicate good water quality within the reservoirs, as both FP @ DH and HB @ DH were oligotrophic and SB @ DH was low in the mesotrophic zone (Table 1 and Figure 7). The TSI dropped considerably from the Hobbs upper basin to the lower basin, indicating that biomass and sediment settled and/or became diluted as water traveled through the basins. The Stony Brook Reservoir was more productive in 2015 than the Hobbs Brook Reservoir, although the higher productivity was not present at Fresh Pond, where nearly all surface and bottom chl-*a* readings were below the detection limit of 2 mg/m^3 (Appendix D). The surface chl-*a* readings from HB @ DH were also below the detection limit, meaning that the reservoirs could be more oligotrophic than depicted since a proxy value of 2 mg/m^3 was used to conservatively estimate TSI. The 2015 chlorophyll-*a* concentrations, TP concentrations, secchi depths, and corresponding TSI values are provided in Appendix D.

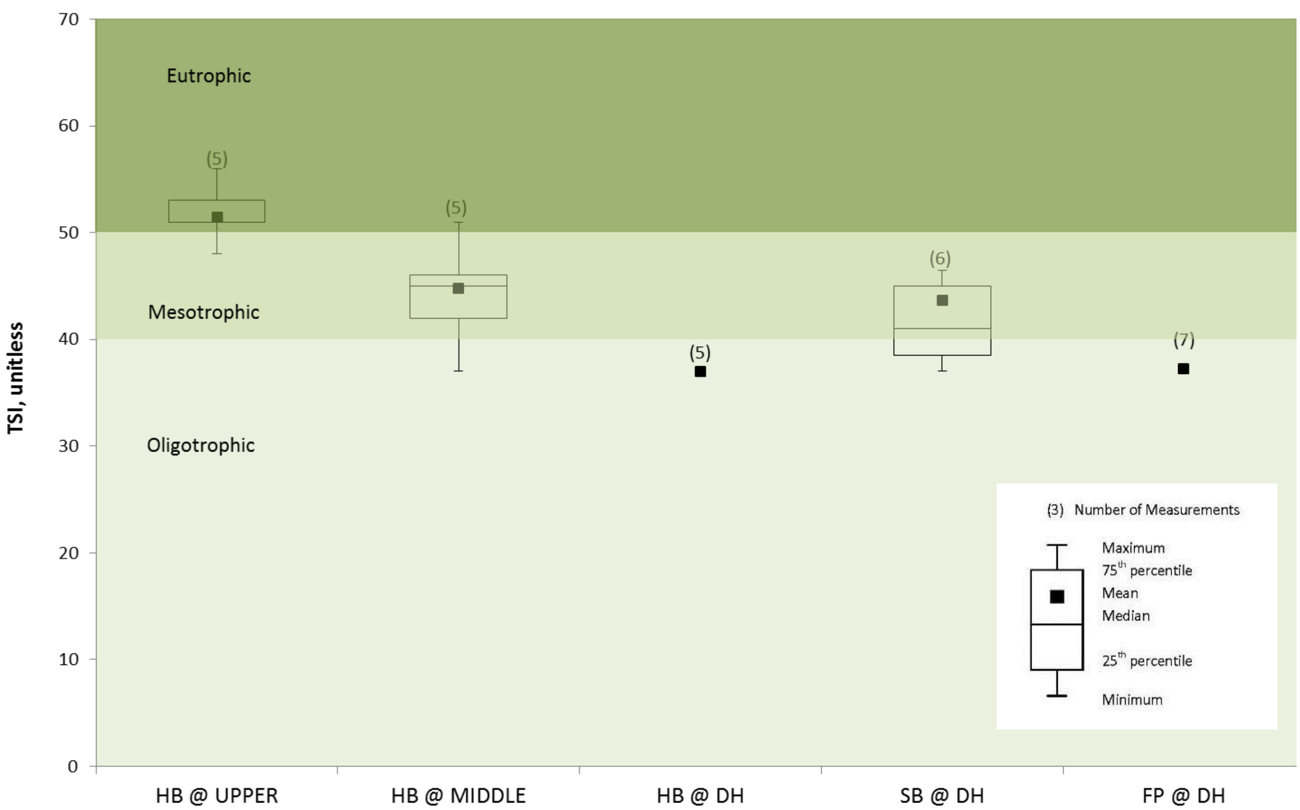

Figure 7. Reservoir Trophic State Index (TSI), from Surface Samples of Chlorophyll-a and TP, 2015. TP was used to calculate TSI during one sample event at HB @ Upper and HB @ Middle on June 25, 2015 since chl-*a* samples were not collected on that date. All other TSI values were calculated using chl-*a*.

Water quality surface samples collected for color, TOC, turbidity, and nutrients also indicate that the Hobbs Brook upper basin was the most productive reservoir site while the HB @ DH was the least productive, demonstrating an improvement in water quality (Tables 9 and 10). In fact, all parameters measured were highest at the HB @ Upper and lowest at the either the HB @ DH site or FP @ DH site with a few notable exceptions.

Table 9. Median Surface Color, TOC, and Turbidity in the Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs, 2015

Parameter	Hobbs Brook Reservoir				Stony Brook Reservoir		Fresh Pond Reservoir
	HB @ Upper	HB @ Middle	HB @ DH	HB @ Intake	SB @ DH	SB @ Intake	FP @ DH
Color (CU)	56	37	8	10	14	16	11
TOC (mg/L)	6.0	4.3	2.6	2.8	3.1	3.2	2.8
Turbidity (NTU)	3.09	1.74	0.47	0.65	0.70	0.90	0.52

The highest median value for each parameter is shaded in red. The lowest median value for each parameter is shaded in blue.

Table 10. Median Nutrient and Chl-*a* Concentrations in the Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs, 2015

Parameter	Hobbs Brook Reservoir				Stony Brook Reservoir		Fresh Pond Reservoir
	HB @ Upper	HB @ Middle	HB @ DH	HB @ Intake	SB @ DH	SB @ Intake	FP @ DH
NO_3 (mg/L)	**<0.145**	**0.144**	0.014	NS	**0.260**	NS	**0.450**
NH_3 (mg/L)	0.077	0.068	< 0.075	NS	0.084	NS	0.095
TKN (mg/L)	**0.68**	**0.53**	0.30	NS	0.36	NS	≤0.39
TP (mg/L)*	**0.025**	**0.018**	<0.010	NS	<0.010	NS	<0.010
Chl-*a* (mg/m^3)	8.82	4.71	<2.00	NS	2.84	NS	<2.00

The highest median value for each parameter is shaded in red. The lowest median value for each parameter is shaded in blue. Nitrate, TKN, and TP medians that exceed the EPA nutrient criteria are **bolded**.
*The detection limit for TP was 0.010 mg/L, which is above the EPA nutrient criteria. Therefore, it is unknown whether the median concentration was below the EPA nutrient criteria.

First, median nitrate and ammonia levels were highest in the Fresh Pond Reservoir (Table 10). This could be partially attributable to the aeration system causing ammonia to become oxidized and convert into nitrate. However, ammonia and total nitrogen[5] were also higher at FP @ DH. Although nitrogen concentrations were higher at Fresh Pond in 2015, more data is needed to determine whether the elevated concentrations represent a trend. Despite elevated nitrate and ammonia levels at Fresh Pond, TKN, TP, and chl-*a* were relatively low (Table 10).

The second exception is that median sodium and chloride concentrations were highest in the Hobbs Brook reservoir, regardless of the sampling site (Table 11). Minimal differences in concentrations were observed between the upper, lower, and middle basins of the Hobbs Brook Reservoir. This is likely because sodium and chloride are dissolved ions which are not removed from the water column by settling. However, high sodium and chloride median concentrations in the Hobbs Brook Reservoir were diluted by less salty water

[5] Total nitrogen was calculated as the sum of TKN, nitrate & nitrite.

in the Stony Brook subwatershed, with the lowest sodium and chloride concentrations observed at Fresh Pond.

Table 11. Median Salt Surface Concentrations in the Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs, 2015

Parameter	Hobbs Brook Reservoir				Stony Brook Reservoir		Fresh Pond Reservoir
	HB @ Upper	HB @ Middle	HB @ DH	HB @ Intake	SB @ DH	SB @ Intake	FP @ DH
Ca (mg/L)	33	29	26	27	28	28	28
Cl (mg/L)	**255**	248	**251**	244	201	198	184
Na (mg/L)	**141**	**139**	**143**	**137**	**111**	**112**	**109**

The highest median value for each parameter is shaded in red. The lowest median value for each parameter is shaded in blue. Median values exceeding MA SMCL or MA Secondary Drinking Water Guideline criteria are **bolded**.

The FP @ DH site and the HB @ DH site had the lowest levels of iron and manganese (Table 12). The Stony Brook Reservoir, while having relatively low iron levels, had the highest manganese levels of all reservoir sampling sites. This likely is attributable to a difference in the composition of bed sediments between the reservoirs (Waldron and Bent, 2001). Interestingly, the median manganese concentration at the Fresh Pond Reservoir, which is fed by the Stony Brook Reservoir, was approximately 50 percent lower than the Stony Brook deep hole and intake sites. This could be due to the Fresh Pond aeration system, which may result in the oxidation of manganese, thereby removing it from the water column.

Table 12. Median Metal Surface Concentrations in the Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs, 2015

Parameter	Hobbs Brook Reservoir				Stony Brook Reservoir		Fresh Pond Reservoir
	HB @ Upper	HB @ Middle	HB @ DH	HB @ Intake	SB @ DH	SB @ Intake	FP @ DH
Al (mg/L)	0.1475	0.1020	<0.0011	0.0068	0.0046	0.0110	0.0135
Fe (mg/L)	**1.00**	**0.518**	0.135	0.133	0.170	0.206	0.103
Mn (mg/L)	**0.095**	**0.075**	0.023	0.024	**0.092**	**0.102**	0.047

The highest median value for each parameter is shaded in red. The lowest median value for each parameter is shaded in blue. Median values exceeding MA SMCL criteria for Fe and Mn are **bolded**.

Tributary Base-flow Water Quality

Through the tributary monitoring program, water quality samples are collected and analyzed for bacteria, salts, nutrients, and metals. Additionally, *in situ* measurements are taken concurrently with a calibrated water quality multiprobe for temperature, pH, specific conductance, TDS, and DO. Each of the 12 tributary monitoring sites (Figure 3) was monitored five to six times during base-flow conditions in 2015. The following sections highlight select results.

Tributary Base-flow Water Quality Overview

When compared against Massachusetts Class A water quality standards, tributary water samples in 2015 were overall of good quality. Twenty percent of samples violated the Class A standard for *E. coli*, although only MBS and WA-17 had median *E. coli* levels exceeding 235 MPN (Table 13 and 14). Less than 15 percent of samples were outside the Class A thresholds for DO and pH. The temperature threshold of 28.3 degrees C for warm water fisheries was not exceeded during the 2015 sampling events, although the cold water fishery temperature standard of 20° C applicable to SB @ Viles and Rt 20 was exceeded in 5 of 12 sampling events (Table 13). According to the Class A regulations, an exceedance of the 20 degree C temperature threshold should be calculated using the seven day average of the maximum daily temperature, not a single point measurement of temperature. Therefore, to confirm the temperature exceedances observed during the tributary sampling visits, a running seven day average of the maximum daily temperature in 2015 was calculated using approved and provisional temperature data collected every 10 minutes by the USGS. Based on these calculations, the temperature threshold was exceeded 119 times at Rt 20 and 67 times at SB @ Viles. It is unknown whether these violations represent natural variations or are exacerbated by anthropogenic factors, such heated pavement runoff or loss of vegetated stream cover.

MA SMCLs for chloride, manganese, iron, TDS and the MA Secondary Drinking Water Guideline for sodium were regularly exceeded during 2015 sampling events (Table 13). Half of tributary samples and sample medians exceeded the chloride SMCL, and 100 percent of samples exceeded the MA Secondary Drinking Water Guideline for sodium, indicating widespread salt impairment (Tables 12 and 13). Median salt concentrations at all tributaries in the Hobbs Brook Reservoir subwatershed exceeded the SMCL for chloride with the exception of HB @ Mill St. All sites in the Stony Brook Reservoir subwatershed had median chloride levels below the SMCL, with the exception of WA-17, which is likely influenced by salt impacted groundwater from the highway. The median chloride level for HB @ KG was at the SMCL, likely due to the influence of water released from the Hobbs Brook Reservoir.

Samples exceeded the TDS standard in 66 percent of samples. The exceedance rates for the nuisance metals iron and manganese, while high (between 80 and 90 percent of all samples and nearly all site medians), were likely due to naturally occurring deposits in sediments since tributary waters were rarely anoxic.

Watershed nutrient levels indicate anthropogenic impacts. Over half of all samples and six site medians exceeded the EPA regional nutrient criteria for nitrate. All site medians exceeded the EPA criteria for TKN and half of all site medians exceeded the criteria for TP (Table 13 and 14). Interestingly, Summer St had the highest nitrate levels of all sampling locations while having the lowest concentrations in the watershed for many of the other parameters measured. The high nitrate is likely caused by septic systems, residential fertilizer, and fertilizer from a recreational golf course located within the subcatchment. Sites with high TP levels tended to be located downstream of wetlands, so a portion of the elevated TP levels could be naturally occurring due to organic matter from the wetlands. WA-17 tributary water is now routed through a constructed wet pond/wetland designed to treat highway stormwater runoff. As a result, median baseflow TP concentrations are now above the EPA criteria (Table 14) indicating that the pond is exporting phosphorus.

Table 13. Summary of Exceedances for Primary Tributaries, 2015

Standard	Parameter	Standard	Number of Samples	Number Exceedances	Percent Exceedances
MA Class A Water Quality	DO	> 5 mg/L	58	8	14%
	DO- Cold Water Fisheries	> 6 mg/L	12	0	0%
	Temperature	< 28.3 °C	58	0	0%
	Temperature- Cold Water Fisheries	< 20.0 °C	12	5	42%
	pH	Between 6.5 - 8.3	70	3	4%
	E. coli, single sample	< 235 MPN	70	14	20%
MA Secondary Maximum Contaminant Level (SMCL)	Cl^-	< 250 mg/L	70	35	50%
	Mn	< 0.05 mg/L	69	61	88%
	Fe	< 0.3 mg/L	69	55	80%
	TDS	< 500 mg/L	70	46	66%
MA Secondary Drinking Water Guidelines	Na^+	< 20 mg/L	69	69	100%
EPA Nutrient Criteria for Upper Watershed	$NO_3^- + NO_2^-$	< 0.31 mg/L	70	37	53%
	TKN	< 0.30 mg/L	70	64	91%
	TP	< 0.02375 mg/L	70	31	44%
	Turbidity	< 1.68 NTU	70	22	31%

Table 14. Primary Tributary Median Base-flow Concentrations [mg/L], 2015

	HB @ MILL ST	SALT DEPOT	LEX BROOK	TRACER LANE	HB BELOW DAM	INDUST BROOK	SB @ VILES	HB @ KG	MBS	WA-17	RT 20	SUMMER ST
Al	0.173	0.087	0.010	0.108	0.004	0.121	0.020	0.076	0.101	0.212	0.054	0.038
Alkalinity (mg/L $CaCO_3$)	34	49	57	70	27	64	31	27	34	67	30	38
Ca	27	67	64	52	26	80	27	28	27	79	30	24
Cl^-	127	**507**	**795**	**406**	**254**	**561**	112	250	197	**449**	238	84
DO	7.86	8.61	8.56	5.39	8.50	5.84	9.07	9.44	**1.94**	8.06	8.62	9.69
E. coli (MPN)	**236**	107	104	209	1	100	73	26	64	**339**	85	53
Fe	**1.20**	**0.91**	**0.50**	**2.03**	0.16	**1.68**	**0.30**	**0.55**	**0.62**	**0.72**	**0.65**	**0.35**
Mn	**0.08**	**0.62**	**0.38**	**0.54**	**0.13**	**0.70**	0.04	**0.26**	**0.13**	**0.34**	**0.22**	**0.06**
Na^+	**73**	**277**	**483**	**234**	**140**	**313**	**51**	**138**	**109**	**246**	**138**	**50**
NO_3^-	0.24	0.14	**0.66**	**0.56**	0.02	**0.39**	**0.86**	0.09	0.02	**0.98**	0.18	**1.80**
NH_3	0.11	0.15	0.10	0.13	0.10	0.36	0.08	0.08	0.10	0.18	0.11	0.11
pH	7.02	7.14	7.12	6.74	7.53	7.09	7.23	7.46	6.71	7.16	7.33	7.78
SpC (uS/cm @ 25ºC)	547	1,734	2,680	1,429	900	2,164	452	900	723	1,693	876	405
TDS	350	**1,109**	**1,715**	**915**	**576**	**1,385**	289	**576**	462	**1,083**	**561**	259
TKN	**0.60**	**0.38**	**0.35**	**0.50**	**0.38**	**0.69**	**0.49**	**0.36**	**0.63**	**0.56**	**0.41**	**0.46**
TOC	7.4	2.7	1.5	3.0	2.5	1.8	5.1	2.5	7.2	1.7	2.8	2.5
TP	**0.037**	**0.026**	0.011	**0.038**	<0.011	**0.039**	0.016	0.019	**0.027**	**0.032**	0.018	0.018
Turbidity (NTU)	**2.30**	1.52	1.11	**4.17**	0.95	**4.32**	0.67	1.11	1.37	**1.92**	1.09	0.61

BOLD: Exceeds Massachusetts Class A Water Quality Standard, SMCL, Secondary Drinking Water Guideline, or EPA Nutrient Criteria

Tributary Wet Weather Monitoring

Stormwater runoff disproportionally impairs water bodies in developed watersheds. Impervious surfaces such as parking lots and roadways store metals, oils, and sediments from cars, aerial deposition, and other sources, which, during storms, are rapidly shunted to streams via piped drainage networks at erosive velocities. In undeveloped watersheds, trees, uncompacted soils, and vegetation capture and recharge most of the stormwater runoff. The small amount of water that flows to streams as runoff does not exacerbate erosion and is generally of good quality.

Since the Cambridge watershed is relatively developed, increases in constituent concentrations such as TP are observed in stream flows dominated by stormwater. However, pollutants that are present in high levels in groundwater, such as sodium and chloride, can become diluted during heavy rain events. Several USGS continuous monitoring stations are outfitted to automatically sample storm events. USGS stormwater automated samples are taken throughout the entire storm, mixed together, and then analyzed for a variety of chemical and nutrient parameters. The stormwater sampling data are available online by station ID number.[6] Between April and December 2015, the USGS sampled between one and seven storm events at each of the following sties: HB @ Mill St, Lexington Brook, Tracer Lane, WA-17, and Summer St. The stormwater chloride, calcium, sodium, and TP concentrations are compared to CWD base-flow samples in Figures 8 - 11.

Sodium, calcium, and chloride concentrations in watershed catchments with high percentages of roadway areas (Lexington Brook, Tracer Lane, WA-17) were reduced during storm events due to dilution from runoff (Appendix E, Figures 8 - 10). Variation in sodium, chloride, and calcium concentrations between dry and wet sampling efforts were minimal in less developed catchments such as HB @ Mill St and Summer St.

[6] The USGS has complied and analyzed stormwater samples from 2005-2007 that is available as in an interpretive report, *Water-quality conditions, and constituent loads and yields in the Cambridge drinking-water source area, Massachusetts, water years 2005–07*.

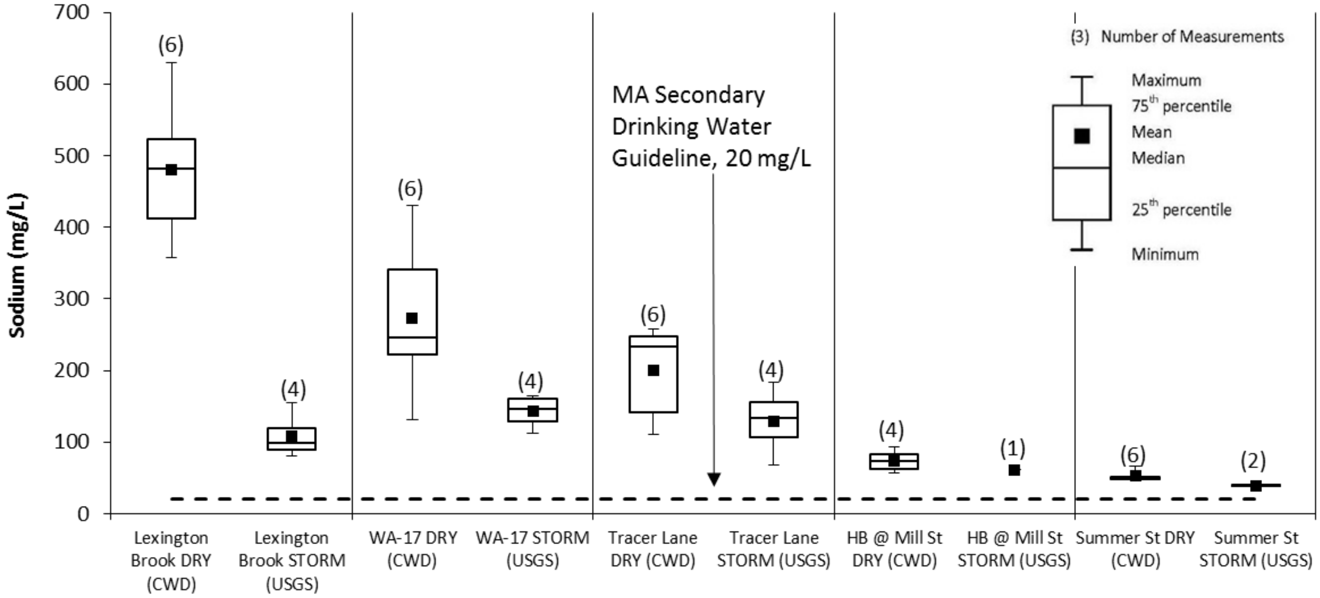

Figure 8. Comparison of Sodium Concentrations in CWD Base-flow and Preliminary USGS Stormflow Data, 2015

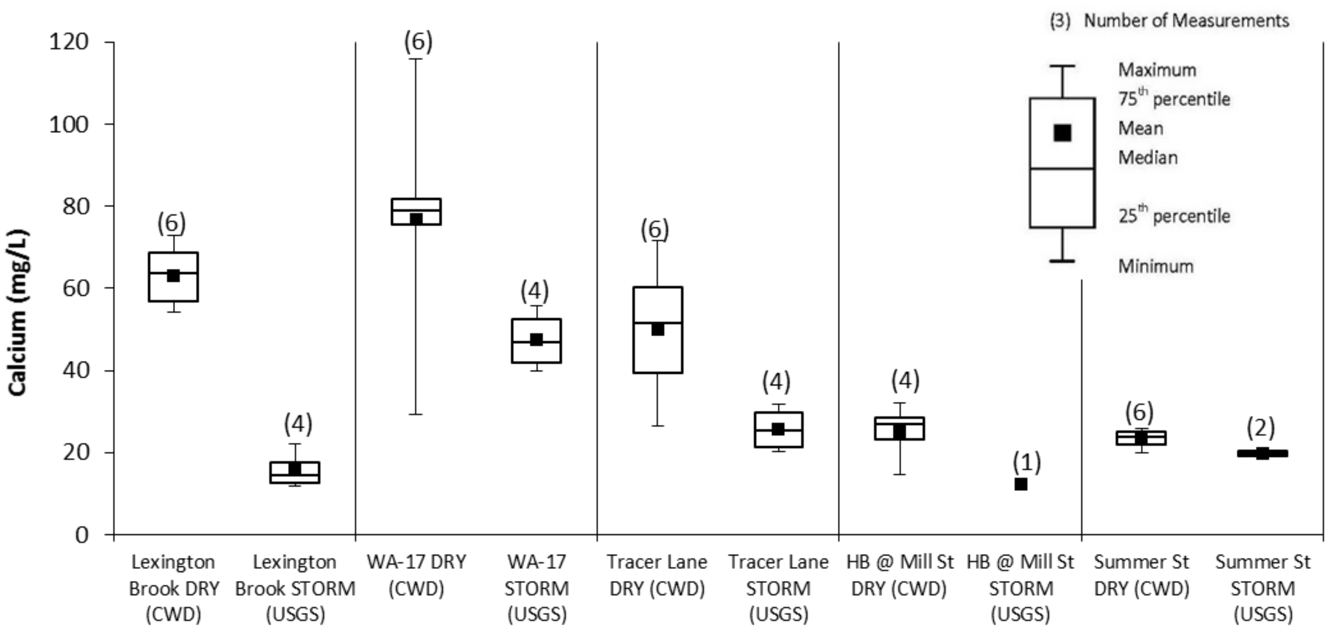

Figure 9. Comparison of Calcium Concentrations in CWD Base-flow and Preliminary USGS Stormflow Data, 2015

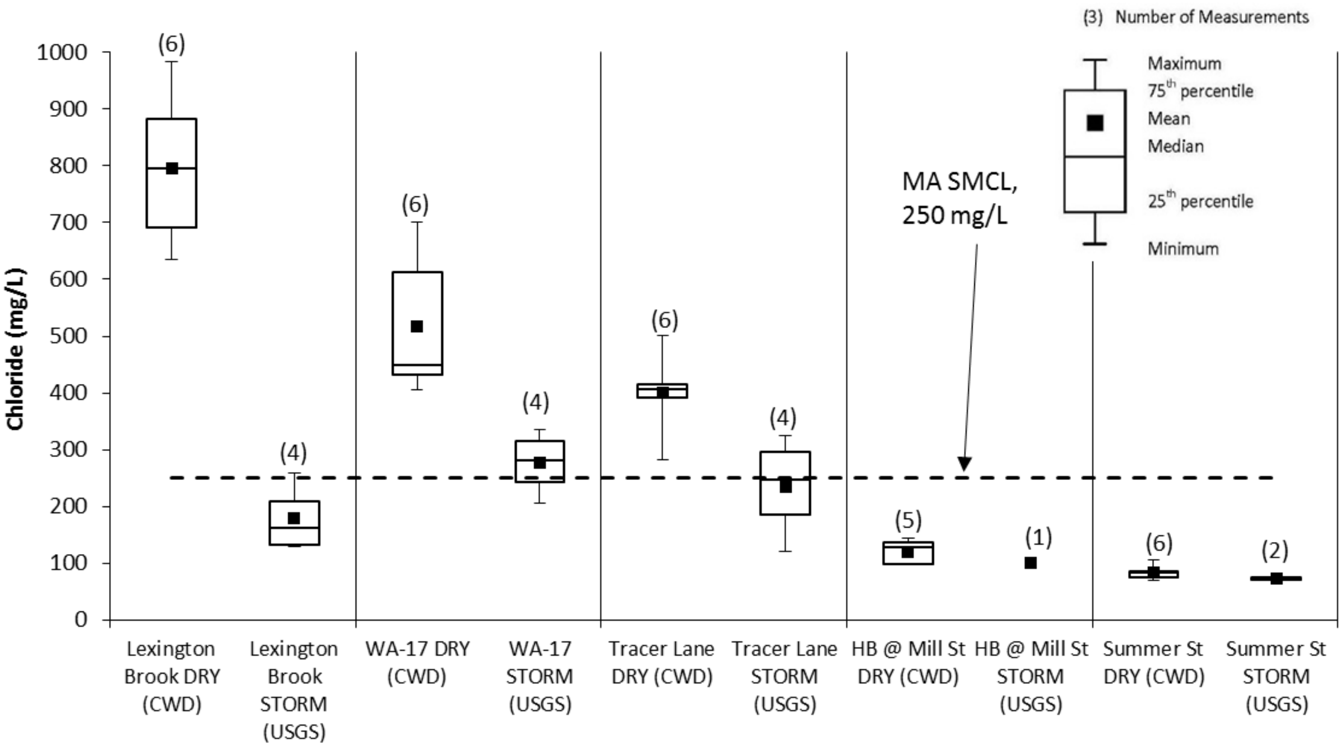

Figure 10. Comparison of Chloride Concentrations in CWD Base-flow and Preliminary USGS Stormflow Data, 2015

Total phosphorus concentrations were higher in stormflow samples than in base-flow at every monitoring location sampled in 2015. Common sources of TP in the watershed include the use of fertilizers, the natural weathering of rocks and soils, and septic tank leaks and failures. Phosphorus tends to stay in the particulate phase, and is thus introduced to the water supply most commonly in runoff (Smith, 2013). As of June 05, 2016, new regulations from the Massachusetts Department of Agricultural Resources prohibit the application of phosphorus containing fertilizers on lawns and turf fields unless soil tests indicate a phosphorus deficiency. It is too soon to determine whether these regulations will have a noticeable impact on TP levels in the watershed.

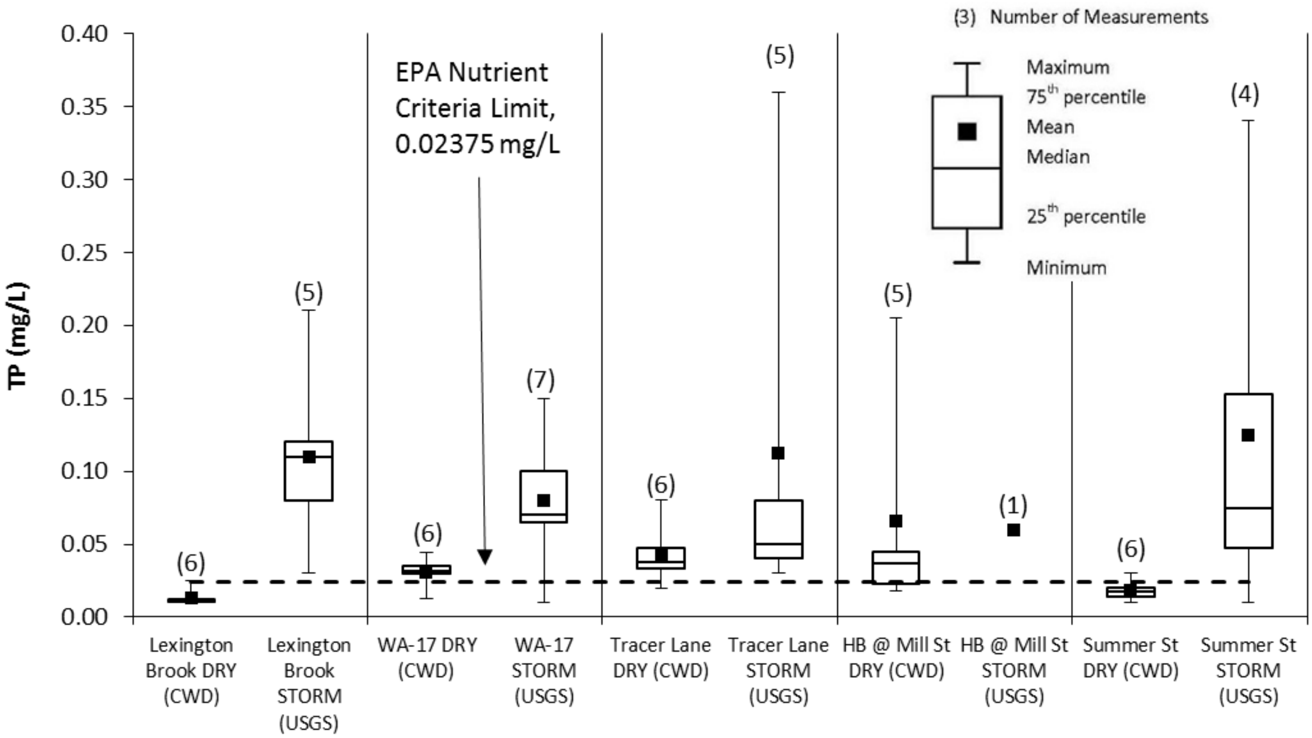

Figure 11. Comparison of Total Phosphorus Concentrations in CWD Base-flow and USGS Preliminary Stormflow Data, 2015. Samples below the detection limit of 0.01 mg/L are displayed at the detection limit.

Load and Yields

Loads and yields of sodium, chloride, nitrate, and TP were calculated for all tributaries entering the Hobbs and Stony Brook Reservoirs. Understanding the contribution of each tributary to reservoir pollutant loads can help prioritize and target management activities within the watershed.

In 2015, the Stony Brook Reservoir received annual tributary pollutant loads of sodium, chloride, nitrate, and TP that were four to seven times higher than the Hobbs Brook Reservoir. This is due to the fact that the Stony Brook Reservoir has a larger drainage area (17 mi^2, 24 mi^2 including the Hobbs drainage area) than the Hobbs Brook Reservoir (7 mi^2) and receives a greater volume of water as a result. Nearly 40 percent of tributary water entering the Stony Brook Reservoir was attributable to releases from the Hobbs Brook Dam in 2015.[7] As such, the quality of water leaving the Hobbs Brook Reservoir has implications on water quality in the Stony Brook Reservoir.

The stormflow contribution of sodium, chloride, nitrate, and TP loads was higher at Hobbs than at Stony, although base-flow contributed the majority of the chemical loads in both basins (Figure 12). In 2014, 64 percent of the Hobbs Brook Reservoir TP load was attributable to stormflow (CWD, 2014). However, in 2015, stormflow accounted for only 48 percent of the TP load (Figure 12). The reduced stormflow contribution could be due to the fact that 2015 was a drier than average year (Table 16, Reservoir Retention Time), thereby reducing the amount of stormflow available to transport TP into the reservoirs. Given that nearly half of TP loads were attributable to stormflow in 2015, stormwater management remains an important watershed protection strategy.

Rt 20 was by far the largest contributor of sodium, chloride, nitrate, and TP due to its large drainage area (Appendix E, Figure 13). However, on a per area basis, Lexington Brook, WA-17, and Tracer Lane were the largest contributors of TP, sodium, and chloride when combining stormflow and base-flow yields (Figure 14). Summer St had the highest yield for nitrate, likely attributable to fertilizer use at a golf course and at residences and septic leachate within the catchment area. WA-17 had the second highest nitrate yield, which is likely due to nutrient export from a stormwater pond at the Rt 20/95 interchange which became active in October of 2012.

[7] Water released from the Hobbs Brook Reservoir dam were considered base-flow in this analysis. However, the discharge is actually the result of both stormflow and base-flow stored and mixed in the Hobbs Reservoir.

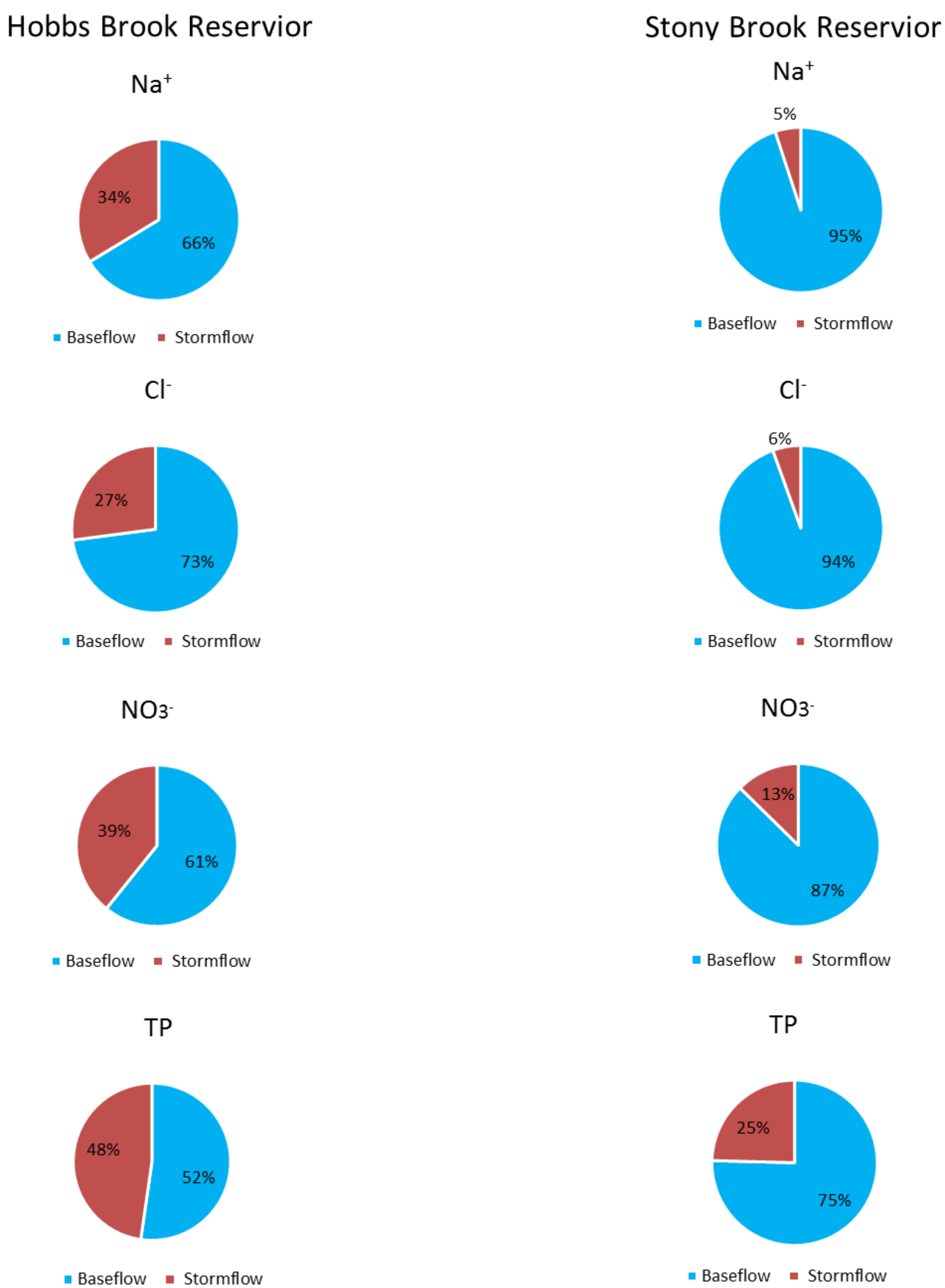

Figure 12. Base-flow and Stormflow Na^+, Cl^-, NO_3^- and TP Load Comparison at Hobbs and Stony Brook Reservoirs, 2015

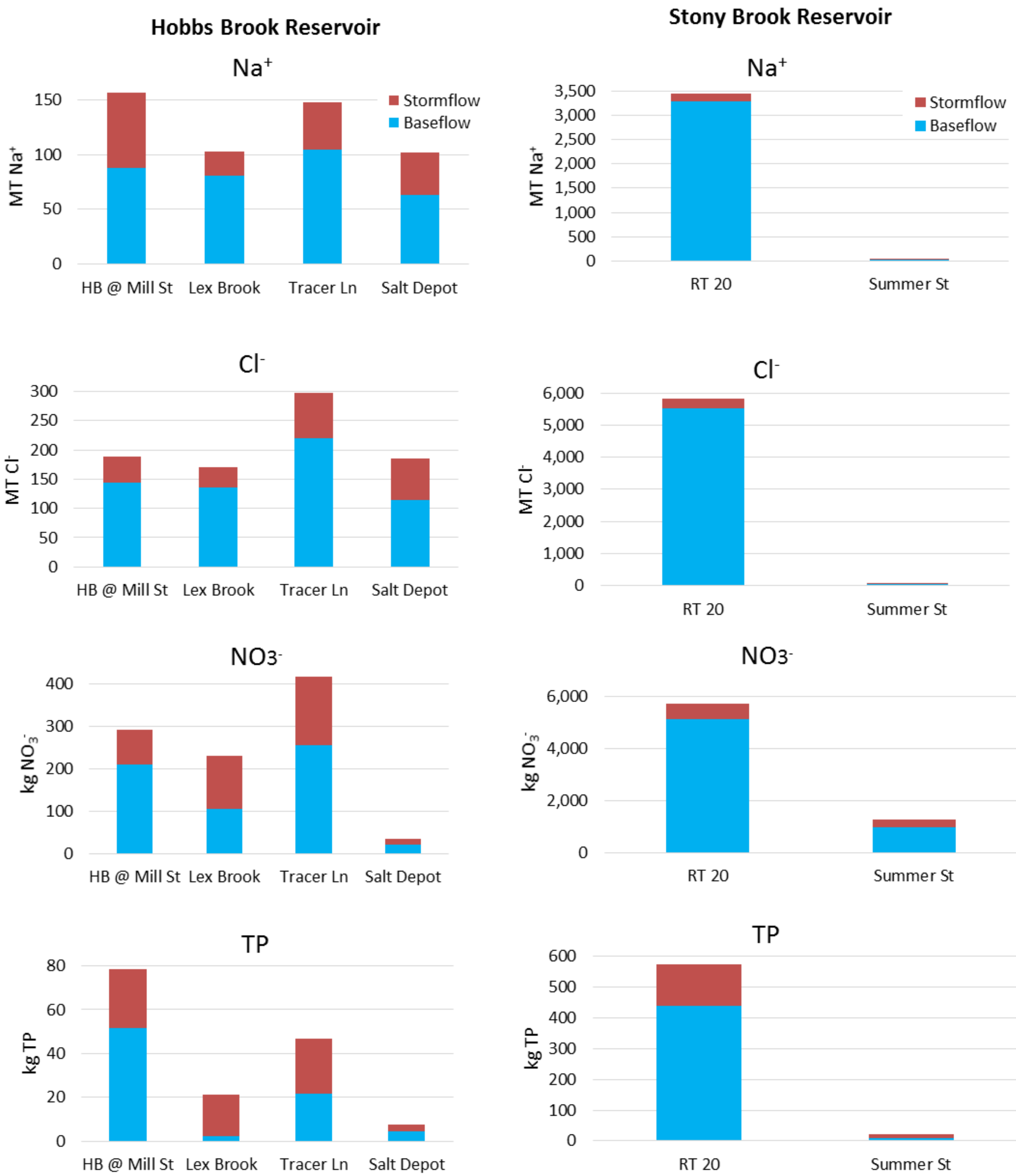

Figure 13. Comparison of Stormflow and Base-flow Na+, Cl-, NO_3^-, and TP Loads in Gauged Hobbs and Stony Brook Reservoir Tributaries, 2015

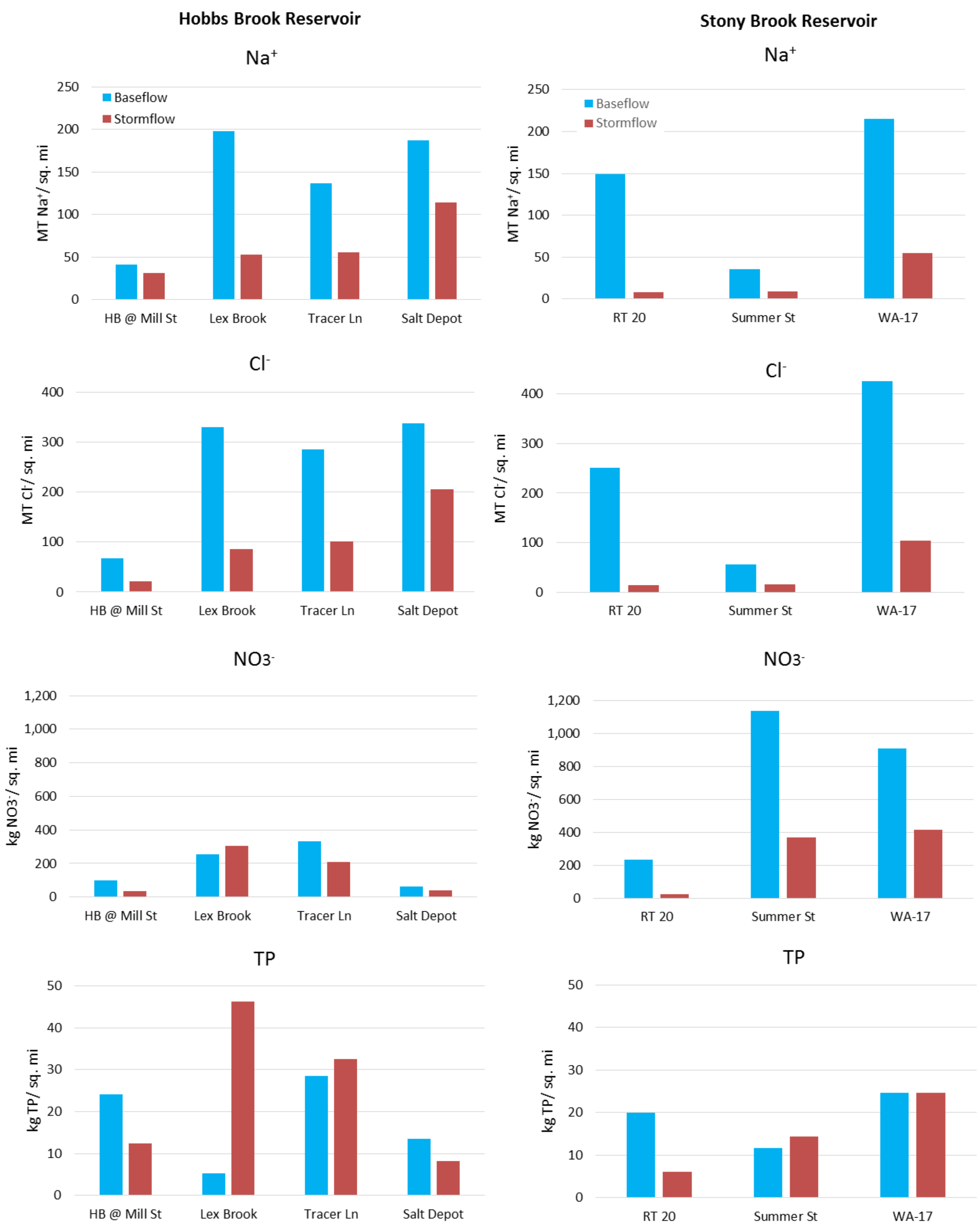

Figure 14. Comparison of Base-flow and Stormflow Na^+, Cl^-, NO_3^-, and TP Yields in Gauged Hobbs and Stony Brook Reservoir Tributaries, 2015

Reservoir Retention Time

Available Water

The reservoir hydraulic retention time is the amount of time necessary for the reservoir to empty if all inputs of water to the reservoir ceased. The retention time is a useful management tool for estimating overall water availability. Reservoir retention times were estimated under the assumption that inputs and outputs to the reservoirs were equal, although small sources of outputs such as losses to groundwater and evapotranspiration were not included in this analysis.

The retention time at the Hobbs Brook Reservoir was calculated using the total storage capacity of 2.52 billion gallons for 2010-2012 and 2.89 billion gallons for 2008-2009. The difference in storage capacity is due to the removal of spillway flash boards at the Hobbs Brook Dam in 2010. The flash boards were replaced in 2015[8] increasing the storage capacity back to 2898 million gallons. The annual outflow estimated from the USGS monitoring station immediately downstream of Hobbs Brook in 2015 was 2.86 billion gallons (Table 15). The hydraulic retention time was 12 months in 2015 and 13 months for the eight-year average.

Table 15. Hobbs Brook Reservoir Retention Time 2008-2015

Year	Hobbs Outflow (MG)	Storage Capacity (MG)	Estimated Retention Time (months)
2008	2,464	2,898	14
2009	3,613	2,898	10
2010	4,889	2,518	6
2011	2,653	2,518	11
2012	1,806	2,518	17
2013	1,431	2,518	21
2014	2,565	2,518	12
2015*	2,859	2898	12

*provisional USGS data, subject to revision

Data from the Cambridge Reservoir meteorological station (422518071162501) indicate that the Hobbs Brook and Stony Brook watersheds received an estimated 40.87 inches of rain (Table 16). This is over eight inches less than the 48.82 inch NOAA 1981-2010 Climate Normal for precipitation at the Bedford, MA station[9].

[8] The flashboards were replaced between 2014 and 2015, although the exact timing of the replacement is unknown. These calculations assume the replacement did not occur until 2015.
[9] http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

Table 16. Hobbs Brook Below Dam Precipitation Gage (01104430) Total Annual Precipitation (Inches)

Year	2008	2009	2010	2011	2012	2013	2014	2015*
Total Precipitation	62.73	40.53	53.51	57.04	43.8	40.17	48.31	40.87

*Provisional data from USGS meteorological station 422518071162501. Data from the precipitation gage at 01104430 station was missing from February 18th through March 3rd.

Inputs to the Stony Brook Reservoir are contributed mostly by its watershed during winter and spring and from the Hobbs Brook Reservoir during the summer and fall. Outflow to the Charles River was estimated from the USGS gaging station located downstream of the Stony Brook gatehouse. Due to the small reservoir storage capacity and large drainage area of Stony Brook, the amount of water released to the Charles River typically exceeds the amount of water diverted to Fresh Pond. However, due to drier than average conditions in 2015, the amount of flow diverted to Fresh Pond via a conduit was more than twice the flow released to the Charles River (Table 17). The estimated retention time in Stony Brook Reservoir was 18 days in 2015, the shortest retention time of all three reservoirs in the Cambridge water supply system.

Table 17. Stony Brook Reservoir Retention Time, 2011-2015

Year	Stony to Charles (MG)	Stony to Fresh Pond (MG)	Total Output from Stony (MG)	Storage Capacity (MG)	Estimated Retention Time (days)
2010	10,514	Data not available	Data not available	418	--
2011	7,663	4,899	12,562	418	11
2012*	2,177	5,256	7,433	418	22
2013*	4,220	4,098	8,318	418	18
2014*	5,473	4,317	9,790	418	15
2015**	2,375	5,691	8,066	418	18

*Conduit data provisional from 2012-2015
**All data provisional, subject to revision

Total output from Fresh Pond to the treatment plant (estimated from the total water produced by the plant) was 3.6 billion gallons in 2015, with a retention time of 3.6 months (Table 18). The eight-year average retention time is approximately four months.

Table 18. Fresh Pond Reservoir Retention Time, 2008-2015

Year	Fresh Pond to WTP (MG)	Storage Capacity (MG)	Estimated Retention Time (months)
2008	4,878	1,507	3.7
2009	4,748	1,507	3.8
2010	4,850	1,507	3.7
2011	4,709	1,507	3.8
2012	4,749	1,507	3.8
2013*	3,552	1,507	5.0
2014*	3,764	1,507	4.8
2015*	5,068	1,507	3.6

*Due construction and maintenance projects, supplemental MWRA was used early September-December 2013, January-May of 2014, and June and August 2015.

In 2015, the Cambridge reservoirs had a combined retention time of 16 months. Therefore, a prolonged multi-year drought could necessitate supplementing Cambridge source water with MWRA water.

References

Edwards, T.K., and Glysson, G.D., 1999, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, chap. C2, book 3, 89 p.

Cambridge Water Department (CWD), 2014, City of Cambridge Water Department 2014 Source Water Quality Report, 90 p. https://www.cambridgema.gov/Water/watershedmanagementdivision/sourcewaterprotectionprogram/sourcewaterqualitymonitoringprogram/datamanagement/reportsandresearch

Sloto, A.S., and Crouse, M.Y, 1999, HYSEP: A Computer Program for Streamflow Hydrograph Separation and Analysis: U.S. Geological Survey Water-Resources Investigations Report 96-4040, 46 p.

Smith, K.P., 2013, Water-quality conditions, and constituent loads and yields in the Cambridge drinking-water source area, Massachusetts, water years 2005–07: U.S. Geological Survey Scientific Investigations Report 2013-5039, 73 p., http://pubs.usgs.gov/sir/2013/5039/.

Waldron, C., Bent, G.C., 2001, Factors affecting reservoir and stream-water quality in the Cambridge, Massachusetts, drinking-water source area and implications for source-water protection. U. S. Geological Survey Scientific Investigations Report 2000-4262, 89 p.

Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T., 1999, Collection of water samples, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, 103 p.

U.S. Environmental Protection Agency, 2000, Ambient water quality criteria recommendations, information supporting the development of state and tribal nutrient criteria, rivers and streams in nutrient ecoregion XIV: Washington, D.C., U/S. Environmental Protection Agency, Office of Water, December 2000, EPA 8822–B–00–022 [variously paginated].

U.S. Environmental Protection Agency, 2001, Ambient water quality criteria recommendations, information supporting the development of state and tribal nutrient criteria, lakes and reservoirs in nutrient ecoregion XIV: Washington, D.C., U/S. Environmental Protection Agency, Office of Water, December 2000, EPA 8822–B–01–011 [variously paginated].

Glossary

Algal bloom— The rapid proliferation of passively floating, simple plant life in and on a body of water.

Anoxic— The absence of oxygen; anaerobic.

Benthic sediments— The surface layer and some sub-surface layers of sediment in contact with the bottom zone of a water body, such as a lake or ocean.

Discharge (hydraulics)— Rate of flow, especially fluid flow; a volume of liquid passing a point per unit of time, commonly expressed in cubic feet per second, million gallons per day, or liters per second.

Dissolved oxygen (DO) — Oxygen dissolved in water; one of the most important indicators of the condition of a water body. Dissolved oxygen is necessary for the life of fish and most other aquatic organisms.

Drainage basin— Land area drained by a river or stream; watershed.

Epilimnion— Warm, oxygen-rich, upper layer of water in a lake or other body of water, usually seasonal. *See also* Metalimnion, Hypolimnion

Eutrophic— Term applied to a body of water with a high degree of nutrient enrichment and high productivity.

Eutrophication— Process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

***Escherichia coli* (*E. coli*) bacteria**— Type of bacteria that is found in the human gastrointestinal tract. *E. coli* is commonly used as an indicator of fecal contamination in groundwater, as the result of an improper sewage connection or septic system failure.

Groundwater— In the broadest sense, all subsurface water, as distinct from surface water; as more commonly used, that part of the subsurface water in the saturated zone. *See also* Surface water.

Hypolimnion— Cold, oxygen-poor, deep layer of water in a lake or other water body. *See also* Epilimnion, Metalimnion.

Hypoxic — The deprivation of oxygen compared to how much is required by the system.

Load— Material that is moved or carried by streams, reported as the weight of the material transported during a specific time period, such as kilograms per day or tons per year.

Maximum contaminant level (MCL)— Maximum permissible level of a contaminant in water that is delivered to any user of a public water system, established by a regulatory agency such as the U.S. Environmental Protection Agency. *See also* Secondary maximum contaminant level.

Mean— The arithmetic average obtained by dividing the sum of a set of quantities by the number of quantities in the set.

Median— The middle or central value in a distribution of data ranked in order of magnitude. The median also is known as the 50th percentile.

Mesotrophic— Term applied to a body of water with intermediate nutrient content and intermediate productivity.

Metalimnion— Transition zone between the warm upper layer and the cold deep layer of a lake or other water body, characterized by rapidly decreasing temperature with increasing depth. *See also* Epilimnion, Hypolimnion.

Minimum reporting limit (MRL) — The lowest measured concentration of a constituent that can be reported reliably using a given analytical method.

Monitoring station— A site on a stream, canal, lake, or reservoir used to observe systematically the chemical quality and discharge or stage of water.

Nutrient— An element or compound essential for animal and plant growth. Common nutrients in fertilizer include nitrogen, phosphorus, and potassium.

Oligotrophic— Term applied to a body of water low in nutrients and in productivity.

pH— The logarithm of the reciprocal of the hydrogen ion concentration of a solution; a measure of the acidity (pH less than 7) or alkalinity (pH greater than 7) of a solution; a pH of 7 is neutral.

Phytoplankton algae— Free-floating, mostly microscopic aquatic plants.

Phytoplankton chlorophyll-*a* — Primary light-trapping pigment in most phytoplankton algae. Concentration can be used as an indirect indicator of the abundance of phytoplankton algae in a lake or other water body.

Runoff— The part of precipitation that appears in surface streams. It is equivalent to streamflow unaffected by artificial diversions, storage, or other human works in or on the stream channel.

Secondary maximum contaminant level (SMCL) — Maximum recommended level of a contaminant in water that is delivered to any user of a public water system. These contaminants affect the esthetic quality of the water such as odor or appearance; therefore, the levels are intended as guidelines. *See also* Maximum contaminant level.

Specific conductance — A measure of the ability of a sample of water to conduct electricity.

Subbasin — Drainage basin or watershed defined by a specific monitoring station and representing the land area that contributes water to that station.

Surface water — An open body of water, such as a stream or lake.

Thermal stratification — Seasonal division of a lake or other water body into a warm upper layer and a cold deep layer that is no longer in contact with the atmosphere. In some lakes, thermal stratification can result in a loss of oxygen in the deep layer and subsequent chemical stratification.

Trihalomethane formation potential (THMFP) — Tendency of naturally occurring organic compounds in a water supply to form toxic trihalomethanes during water treatment.

Trophic state — The extent to which a body of water is enriched with plant nutrients. *See also* Eutrophic, Mesotrophic, Oligotrophic.

Trophic state index (TSI) — A numerical index indicating the degree of nutrient enrichment of a body of water.

Turbidity — The opaqueness or reduced clarity of a fluid due to the presence of suspended matter.

Water year — The continuous 12-month period, October 1 through September 30, in U.S. Geological Survey reports dealing with the surface-water supply. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1998, is referred to as the "1998" water year. This report, however, operates on a calendar year.

Wetlands — Lands that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

Yield — The weight of material transported during any given time divided by unit drainage area, such as kilograms per day per square kilometer or tons per year per square mile.

Appendix A – Water Quality Monitoring Procedure and Schedule

Monitoring Objectives

Given the City's lack of ownership and control of most watershed lands, water quality monitoring is a necessary and effective means of identifying sources of pollution and tracking water quality changes over time. The primary goal of the Cambridge Source Water Quality Monitoring Program is to ensure that water withdrawn from Fresh Pond Reservoir for treatment is as free as possible from contaminants, thereby minimizing the costs of treatment and protecting overall water quality. Specific objectives of the program are to:

- Monitor the condition of source waters in the Cambridge drinking water supply system;
- Determine where, when, and how water quality conditions are changing over time;
- Identify actual and potential problems related to source water quality;
- Evaluate the effectiveness of programs designed to prevent or remediate water quality problems;
- Ensure that all applicable water quality goals, standards, and guidelines are being met; and
- Provide for rapid response to real-time and emerging problems.

The Cambridge Source Water Quality Monitoring Program consists of four major elements: (1) routine monitoring of reservoirs and tributary streams during base-flow (dry weather) conditions, (2) event-based monitoring of streams, storm drains, and other outfalls during wet weather and special water quality investigations, (3) continuous recording of stage and selected water quality characteristics at critical sites within the drainage basin, and (4) data management, analysis, reporting, and review.

Routine Water Quality Monitoring

Under base-flow (dry-weather) conditions, CWD staff members collect discrete grab samples and measure streamflow and in situ parameters (dissolved oxygen, specific conductance, temperature, oxidation-reduction potential, and pH) throughout the watershed at regular intervals during the year. Base-flow sampling, conducted on days with no more than 0.10 in of rain 72 hours prior, provides a representative measurement without the influence of stormwater. Sampling is conducted at 8 reservoir-monitoring stations, and at 12 primary monitoring stations. Table 19 contains all sample dates and locations in 2015.

Routine Reservoir Monitoring

The Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs are all sampled regularly using USGS *Clean Water* sampling protocols. Each reservoir is sampled for nutrients, metals, chlorophyll-*a*, bacteria and in-situ parameters. During summer months, when the water column is thermally stratified, additional water samples at deep hole sites are pumped from below the thermocline (the point of maximum rate of change in water temperature with depth) with a peristaltic pump through pre-cleaned Tygon tubing. Studies conducted by the USGS have shown that under most conditions, water quality data collected in depth profiles at these stations are indicative of conditions throughout the reservoirs.

Samples are analyzed at the CWD laboratory for total organic carbon, color, alkalinity, turbidity, bacteria, concentrations of major ions (sodium, calcium, chloride, and sulfate), and selected metals (aluminum, iron, and manganese) using standard approved methods. Nutrients (ammonia nitrogen, total Kjeldahl nitrogen, and TP) and chlorophyll-*a* are analyzed at contracted laboratories.

Routine Tributary Monitoring

Water entering the reservoirs is monitored at 12 monitoring stations. Specific conductance, pH, water temperature, and dissolved oxygen concentration are measured *in situ* and water samples are collected at the stream channel center in accordance with clean sampling protocols. The samples are analyzed at both CWD and contracted laboratories for the same suite of parameters as the reservoir samples except for chl-*a*.

USGS Continuous-Record Surface-Water Monitoring

In 2015, continuous (10-15 minute interval) monitoring was conducted at nine primary tributary monitoring stations and three reservoir monitoring stations. These stations are operated and maintained by the USGS and CWD for continuous measurement of stream and reservoir stage, discharge (eight sites only), temperature, and temperature-corrected specific conductance. However, discharge measurements at two sites, MBS and HB @ Mill St, were discontinued in October of 2015. For the purposes of calculating loads and yields, discharge at HB @ Mill St was calculated using a rating curve supplied by the USGS and continuous provisional stage readings from the unmaintained site. However, measurements were not taken by the USGS in October to verify the accuracy of the stage-discharge relationship, which may have been altered due to removal of stones that had served as the control for the measurements.

Precipitation was monitored at the three reservoir stations, and wind speed and direction was measured at the Stony Brook reservoir. Continuous water quality parameters such as specific conductance and temperature were collected from all three reservoirs. Continuous discharge measurements from the Hobbs and Stony dams, as well as from the Stony conduit to Fresh Pond, were also collected in 2015.

All continuous monitoring information is uploaded on a real-time basis to the USGS internet site, which can be accessed from the hyperlink below.

http://waterdata.usgs.gov/ma/nwis/current?type=cambrid&group_key=NONE&search_site_no_station_nm=&format=html_table

Table 19. CWD Water Quality Monitoring Schedule, 2015

Primary Tributary Group 1 (5 Sites)	Sampling Dates
HB @ Mill St*	4/2, 6/18, 7/14, 8/18, 9/16, 11/2
Salt Depot	
Tracer Lane	
SB @ Viles	
MBS	

Frequency Target : 8 Events

*Not sampled 6/18/2015 due to beaver flooding

Primary Tributary Group 2 (5 Sites)	Sampling Dates
Lexington Brook	3/12, 5/7, 7/7, 7/29, 9/9, 10/27
HB Below Dam	
WA-17	
Rt 20	
Summer St	

Frequency Target : 8 Events

Primary Tributary and Reservoir Group (4 Sites)	Sampling Dates
Industrial Brook	4/16, 6/25, 7/22, 9/1, 11/10, 12/21
HB @ KG	
HB Middle*	
HB Upper*	

Frequency Target : 8 Events

*HB @ Mid and Upper not sampled 11/10 due to low water level

Upcountry Reservoirs Group (6 Sites)	Sampling Dates*
HB @ DH	6/11, 7/9, 8/6, 9/3, 10/20, 12/1, 12/9
HB @ DH bottom	
HB @ Intake	
SB @ DH	
SB @ DH bottom	
SB @ Intake	

Frequency Target : 8 Events

Fresh Pond Reservoir Group (4 Sites)	Sampling Dates
FP @ DH	3/2, 4/28, 6/24, 8/13, 9/15, 10/21, 12/10
FP @ DH bottom	
FP @ Cove	
FP @ Intake	

Frequency Target : 8 Events

*Hobbs Brook Reservoir sites not sampled 10/20 and 12/9 due to low water level. SB not sampled on 12/1.

Event-Based Water Quality Monitoring

Stormwater Sampling

Wet weather or stormwater sampling by staff in the field can be difficult to schedule due to the unpredictable timing of precipitation events. Thus automatic sampling is a preferred method for obtaining wet weather samples when available. Due to the joint funding agreement with USGS, the city of Cambridge is in a unique position to benefit from continuous monitoring stations set up within the watershed. Stations at HB @ Mill St, Lexington Brook, Tracer Lane, WA-17 and Summer St are equipped with automatic samplers which collect storm water when triggered by unusually high stream flow. USGS storm sample collection dates for 2015 are presented below in Table 20. The range of dates indicates the duration of the storm from which the composite sample was derived.

Table 20. USGS Wet Weather Sampling Dates, 2015

Site	USGS Site ID	Wet Weather Sampling Dates
HB @ Mill St	01104405	4/20-4/22
Lexington Brook	01104415	4/20-4/21 5/31-6/02 9/10-9/11 10/28-10/29 12/01-12/02
Tracer Lane	01104420	4/20-4/22 5/31-6/3 9/10-9/11 10/28-10/30 12/1-12/2
WA-17	01104455	4/20-4/21 5/19-5/19 5/31-6/02 6/15-6/15 9/10-9/11 10/28-10/29 12/01-12/02
Summer St	01104475	4/20-4/22 5/31-6/01 9/11-9/11 12/01-12/02

Incident-Based Sampling

CWD staff perform additional sampling on an as-needed basis to investigate problems associated emergency spills or illicit discharges within the watershed, and to monitor runoff from construction activities. These test results help guide management and enforcement activities within the watershed. Sample results are used to guide spill response actions and are not included in the report.

Data Management, Interpretation, Reporting, and Review

All water quality monitoring and quality-assurance data are entered into a CWD-maintained database that enables the CWD analyze, track, and report changes in water quality efficiently. This report satisfies the reporting portion of the water quality monitoring program.

Appendix B – Quality Control Measures

USGS Side-by-Sides

CWD staff conducted sampling alongside USGS staff at the MBS site on June 18, 2015. Grab samples were taken using the same protocols that CWD follows for routine water quality sampling. Comparing CWD and USGS results of the sampling event can provide a broad measure of the inherent and introduced variability in surface water samples. Variability may be introduced in results from the sample collection, processing, and analysis; from the differences in laboratory analysis techniques or handling; or from the natural variability of concentations in surface waters.

Sampling data was collected from the USGS website and compared to CWD results. The precision of the data is measured using the Relative Percent Difference (RPD) metric. RPD is calculated using the equation

$$RPD = \frac{|x_1 - x_2|}{(x_1 + x_2) * (\frac{1}{2})} * 100\%$$

Where x_1 and x_2 are the sample measurement and corresponding field duplicate. Due to the nature of measurement error and environmental sampling constraints, differences within 20 percent are considered acceptable measurements. The RPD for each parameter is shown in Table 21.

Table 21. USGS Side-by-Side Sample Results and Percent Differences by Parameter

Site	Agency	Date	Water Temp. (°C)	Sensor SpC (μS/cm)	TP (mg/L)	Ca^{2+} (mg/L)	Cl^{-} (mg/L)	Lab Specific Conductance (μS/cm)	Na^{+} (mg/L)	lab turbidity (NTU)
MBS	CWD	6/18/2015	20.02	731	0.035	22.6	202	719	101.0	1.43
	USGS	6/18/2015	20	706	0.039	23.8	187	721	108	1.8
%RPD			**0%**	**3%**	**11%**	**5%**	**8%**	**0%**	**7%**	**23%**

The largest differences were measured with turbidity, which was slightly outside the target range of 20 percent. The discrepancy between CWD and USGS turbidity sample could indicate contamination from suspension of bed sediments due to multiple people working in the stream. It is also easy to disturb the bed sediments at the highly organic MBS site, so extra care should be taken to cause minimal disturbance of the bed sediments in future sampling events. However, from a data interpretation standpoint, a difference of 0.37 NTU is small given that a highly turbid sample could be in excess of 10 NTU.

Field Duplicates and Trip Blanks

Field duplicates and trip blanks provide QC checks in-house for CWD data. Field duplicates were taken at one location during most sampling events to measure the precision of CWD data as well as environmental variability. Trip blanks ensure there is no cross-contamination of the samples during sample transport and processing.

The average RPD between duplicate samples for all tests performed by CWD and Premier Labs was 11 percent and 21 percent, respectively (Table 22). While certain individual tests did have a high RPD, on average the results were within an acceptable range. Large variations between samples and duplicates could represent environmental variation, contamination of the sample, or an error in the laboratory analysis.

Table 22. Average Relative Percent Differences, 2015

RPD	All Samples		Tributaries		Reservoirs	
	Premier	CWD	Premier	CWD	Premier	CWD
All Samples	21%	11%	21%	14%	22%	7%
Min	0%	0%	0%	0%	0%	0%
Max	169%	162%	122%	150%	169%	162%

Trip blanks were included with tributary and reservoir samples on March 2, June 18, and November 2, 2015 (Table 23). Nearly all parameters were below the detection limit, and those parameters that were detected, such as 1.8 mg/L of chloride on 3/2/2015, were not present in quantities large enough to meaningfully affect sample results. The 0.16 mg/L of ammonium detected on 6/18/2015 is likely due to ammonium hydroxide used in the water treatment process that was not removed during deionization. Values for pH, conductivity, and turbidity were within the expected ranges for de-ionized water exposed to the atmosphere. This indicates that discrepancies between samples and FDUPs are unlikely due to contamination during sample transport or processing.

Table 23. Trip Blank Results, 2015

Date	3/2/2015	6/18/2015	11/2/2015
Ca (mg/L)	0.08	<0.020	< 0.005
Cl (mg/L)	1.8	<1.00	0.5
Color (CU)	<1.0	<1.0	< 1.0
Conductivity (umhos/cm)	<1.0	2.3	2.03
E. coli (MPN)	Not sampled	< 1	<1
Mn (mg/L)	<0.000	<0.000	0.00003
NO_3 (mg/L)	<0.005	<0.005	< 0.00
NO_2 (mg/L)	<0.004	<0.004	< 0.00
Lab pH	5.93	5.87	5.88
Na (mg/L)	0.4	<0.020	0.02526
NH3 (mg/L)	<0.05	0.16	<0.05
TKN (mg/L)	<0.1	<0.1	<0.1
TOC (mg/L)	0.2	0.2	0.3
Total Alkalinity (mg/L $CaCO_3$)	<2.0	<2.0	1.5
Total Al (mg/L)	<0.002	<0.002	< 0.0005
Total Coliform (MPN)	Not Sampled	<1	<1
Total Fe (mg/L)	0.08	<0.050	< 0.050
TP (mg/L)	<0.01	<0.01	<0.01
Turbidity (NTU)	0.056	0.061	0.054
UV254 (abs)	0.001	0.003	< 0.001

Appendix C – Base-flow and Stormflow Separation Method

Separation of base-flow from total discharge was performed according to the Fixed Interval Method, whereby the lowest recorded discharge value over a fixed time interval (3 to 11 days) is used to represent base-flow over the entire interval (Sloto and Crouse, 1996). The fixed time interval (2N*) is a function of the drainage area of a catchment, and is calculated by first estimating the recession period for surface runoff following a storm event:

$N=A^{0.2}$

Where:

N=recession period, A=area of catchment (sq. mi)

2N* = the odd integer between 3 and 11 closest to twice the recession period (N*2)

In this study, all catchments had intervals of 3 days. Therefore, base-flow was calculated as the lowest discharge value in each three day period of 2015. For example, base-flow for each day between January 1 and January 3 was assigned based on the minimum value recorded during the interval. The same process was repeated for the next three days, January 4 – January 6. Stormflow was calculated as the difference between total discharge and base-flow.[10] A difference of zero between total discharge and base-flow represents dry conditions with no stormflow. Daily average discharge was used as proxy data during days where instantaneous data were missing from the record.

Annual total discharge, base-flow, and stormflow were calculated by integrating the discharge data for each category[11]:

$Q_{annual} = ((Q_2+Q_1)/2)*(t_2-t_1) + ((Q_3+Q_2)/2)*(t_3-t_2)\ldots+ ((Q_n+Q_{n-1})/2)*(t_n-t_{n-1})$

Where

Q_{annual} = annual total discharge, base-flow, or stormflow in cubic feet per year

Q_n = instantaneous total discharge, base-flow, or stormflow in cubic feet per second

t_n = time and date of discharge measurement, in seconds elapsed since 1/1/1900[12]

Base-flow separation was performed for all sites where USGS instantaneous discharge data were available: Lexington Brook, HB @ Mill St, Salt Depot, Tracer Lane, Rt 20, WA-17, and Summer St.

[10] Discharge at Rt 20 is heavily influenced by upstream releases of water from the Hobbs Dam. Therefore, increases in discharge can be attributable to both storm events and to managed releases of water from dam. To avoid erroneously counting dam releases as stormflow, the daily average discharge measured from the HB Below Dam gage was subtracted from the daily average discharge at Rt 20; stormflow and base-flow calculations were performed using this difference. Discharge from the HB Below Dam gage was assumed to be base-flow at Rt 20 and was added to the annual base-flow total. This differed from 2014, which did not separate dam releases prior to calculating stormflow and base-flow (CWD, 2014).

[11] Instantaneous data at WA-17 was unavailable for nearly all of 2015. Therefore, daily average discharge data in cfs were used to calculate stormflow and base-flow for all of 2015. Rather than integrate the daily data, the average daily discharge was converted into total daily discharge by multiplying by 86,400 (the number of seconds in a day) and summed. The same process was used to calculate total annual stormflow and base-flow for Rt 20.

[12] Dates stored in Excel, when converted to numeric format, represent the number of days have elapsed since 1/1/1900. For example, 1/1/1900 at 00:00 = 0 days, 1/1/2014 at 12:00 = 41,640.5 days. This number can be converted into the number of seconds elapsed since 1/1/1900 by multiplying by 86,400, the number of seconds in a day. Having data in this format allowed for the calculation of the number of seconds elapsed between each discharge measurement (t_n-t_{n-1}).

Appendix D – Reservoir TSI Values

Table 24. Reservoir Chlorophyll-a, Total Phosphorus, Secchi Depth, and Corresponding TSI Value, 2015

	Sampling Date	Chlorophyll-*a* (µg/L)	TSI	Total Phosphorus (mg/L)	TSI	Secchi Depth (m)	TSI
Hobbs Brook at Upper	4/16/2015	5.77	48	0.020	47	NS	--
	6/25/2015	NS	--	0.025	51	NS	--
	7/22/2015	10.00	53	0.022	49	NS	--
	9/1/2015	10.60	54	0.050	61	NS	--
	12/21/2015	7.65	51	0.057	62	NS	--
Hobbs Brook at Middle	4/16/2015	4.46	45	0.018	46	NS	--
	6/25/2015	NS	--	0.014	42	NS	--
	7/22/2015	4.96	46	0.010	37	NS	--
	9/1/2015	10.45	54	0.03	53	NS	--
	12/21/2015	< 2	37	0.031	54	NS	--
Hobbs Brook at Deep Hole Surface	6/11/2015	< 2	37	< 0.010	37	4	40
	7/9/2015	< 2	37	< 0.010	37	5	37
	8/6/2015	< 2	37	0.036	56	5	37
	9/3/2015	< 2	37	0.010	37	5	37
	12/1/2015	< 2	37	< 0.010	37	6	34
Stony Brook at Deep Hole Surface	6/11/2015	< 2	37	< 0.01	37	3.5	42
	7/9/2015	2.04	38	< 0.01	37	3.5	42
	8/6/2015	18.05	59	0.0165	45	3	44
	9/3/2015	2.53	40	0.020	47	3	44
	10/20/2015	3.14	42	0.010	37	3.5	42
	12/9/2015	4.985	46	0.012	38	3	44
Fresh Pond at Deep Hole Surface	3/2/2015	< 2	37	0.01	37	2.5	47
	4/28/2015	2.28	39	< 0.010	37	3	44
	6/3/2016	NS	--	NS	--	2.5	47
	6/24/2015	< 2	37	< 0.010	37	5	37
	8/13/2015	< 2	37	0.011	39	4.5	38
	9/15/2015	< 2	37	< 0.010	37	4	40
	10/21/2015	< 2	37	< 0.010	37	5	37
	12/10/2015	< 2	37	< 0.010	37	6.5	33

Note: the detection limit was used as proxy to calculate TSI for values below detection limit
NS: Not sampled.

Appendix E – Tributary Catchment Area and Land Cover

Table 25. USGS Stations and Corresponding CWD Site Names

	HB @ MILL ST	SALT DEPOT	LEX BROOK	TRACER LANE	HB BELOW DAM	INDUST BROOK*	SB @ VILES	HB @ KG	MBS	WA-17	RT 20	SUMMER ST	STONY BROOK DAM
USGS Site ID	01104405	0110441 0	01104415	01104420	01104430	01104433	01104370	01104440	01104453	01104455	01104460	01104475	01104480
Drainage Area (mi^2)	2.2	0.34	0.41	0.77	6.9	0.36, (0.33)	10.2	8.5	2.2	0.48	22.0	0.85	23.7

***0.33 mi^2 is the effective drainage area of the industrial brook catchment (Smith, 2013)Table 26. 2005 MassGIS Land Use Classification, Percent by Area per USGS Subbasin**

	Sampling Station ID													
2005 MA Land Use	**01104405**	**01104410**	**01104415**	**01104420**	**01104430**	**01104433**	**01104370**	**01104440**	**01104453**	**01104455**	**01104460**	**01104475**	**01104480**	**Watershed Total**
Forest	56.58	50.35	27.05	27.2	32.68	12.13	47.1	49.2	42.3	39.77	23.17	45.07	38.66	43.26
Low Density Residential	7.23	0.14	6.94	7.33	2.59	0.06	18.08	18.75	21.31	0.04	9.41	20.6	19.21	13.86
Forested Wetland	20.79	10.5	0.28	11.16	2.62	8.09	11.49	5.11	9.42	0.92	2.47	3.01	1.13	9.33
Water	0.29			0.13	29.33	0.26	3.78	1.47	0.43	0.17	8.48	1.27	16.31	6.49
Commercial		8.29	3.4	9.26	8.19	35.77	0.82	5.01	1.21	7.92	15.98		1.58	3.32
Cropland	3.17		0.97	0.27	0.05		4.89	1.25	1.21			1.87		2.74
Non-Forested Wetland	1.95	7.26	1.27	1.71	0.84	0.63	3.71	3.41	3.46		4.61	0.63	0.4	2.73
Medium Density Residential			24.46	10.48	9.52		0.33		2.84	6.62	0.15	0.29	0.32	2.69
Very Low Density Residential	3.13	0.01		0.14	0.73		3.89	1.22	3.69	0.25		3.38	0.45	2.66
Transportation		0.1	16.12	6.61	5.89	10.82	0.54	0.04		10.6	4.12		6.27	2.24
Industrial		5.41		5.98	4.92	32.03	0.11	5.7		17.19	3.17	0.04		2.16
Urban Public/Institutional	1.55	4.56	2.24	1.7	0.67	0.21	1.03	1.73	4.58	0.06	1.54	1.38	7.09	1.69
High Density Residential			15.48	16.27	0.07					6.78			7.26	1.24
Pasture	1.58	1.36			0.17		1.27	1.16	1.64			4.23		1.11
Multi-Family Residential			0.09	0.22	0.02		1.22	3.21	0.45	0.48	7.82			0.88
Open Land	1.09	3.68	0.47	1.55	0.37		0.8	0.92	0.87		4.1	0.37	0.56	0.84
Golf Course									1.16			16.75		0.71
Participation Recreation	1.17	0.82	1.22		0		0.49	1.82	2.25			0.61	0.14	0.69
Powerline/Utility	0.08	7.51			1.34		0.13		0.68	7.45	1.86			0.6
Cemetery	0.72								2.17					0.27
Mining									0.36	0.15	12.33		0.32	0.23
Brushland/Successional	0.3						0.02					0.48		0.06
Orchard	0.15						0.07							0.05
Spectator Recreation	0.05						0.08						0.3	0.05
Junkyard										1.61	0.6			0.04
Waste Disposal	0.18						0.06							0.04
Transitional							0.03		0		0.19			0.02
Water-Based Recreation							0.05							0.02